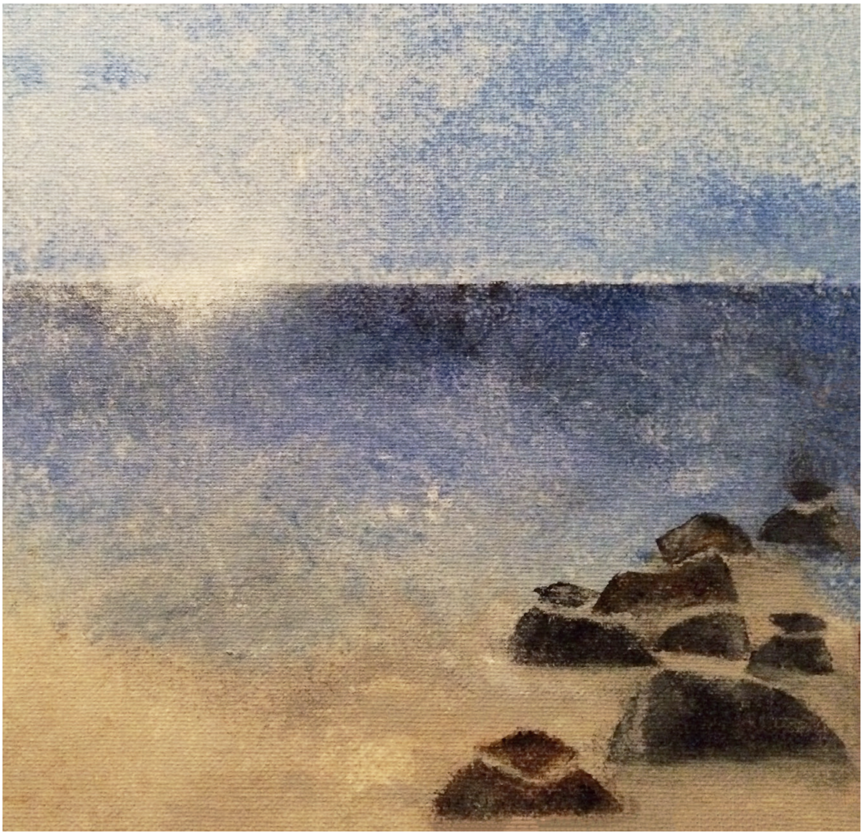
Thesis for doctoral degree (Ph.D.)
2017

Traumatic patellar dislocation in children

epidemiology, risk factors, the MPFL and treatment outcome



Marie Askenberger

Karolinska Institutet

From THE DEPARTMENT OF WOMEN´S AND CHILDREN´S HEALTH
Karolinska Institutet, Stockholm, Sweden

TRAUMATIC PATELLAR DISLOCATION IN CHILDREN
-EPIDEMIOLOGY, RISK FACTORS, THE MPFL AND TREATMENT OUTCOME

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Stockholm 2017

Published by Karolinska Institutet.
Printed by Eprint AB

ISBN 978-91-7676-541-8

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By

Marie Askenberger

Principal Supervisor:
Associate Professor Per-Mats Janarv
Karolinska Institutet
Department of Women´s and Children´s Health
Department of Molecular Medicine and Surgery

Co-supervisor(s):
Ph.D. Wilhelmina Ekström
Karolinska Institutet
Department of Molecular Medicine and Surgery

Professor Lars Weidenhielm
Karolinska Institutet
Department of Molecular Medicine and Surgery

Opponent:
Professor Nils Hailer
Uppsala University
Department of Surgical Science
Division of Orthopedics

Examination Board:
Associate Professor Torkel Brismar
Karolinska Institutet
Department of Clinical Science,
Intervention and Technology

Professor Joanna Kvist
Linköping University
Department of Medical and Health Science
Division of Physiotherapy

Associate Professor Kristian Samuelsson
University of Gothenburg
Department of Orthopedics
Institute of Clinical Sciences

To my family

ABSTRACT

The knee joint is one of the most common injury sites in children, with the spectrum of injuries differing from those in adults. Traumatic lateral patellar dislocation (LPD) is the most common serious injury; the incidence is approximately 1/1000 in children 9-15 years of age. The risk for recurrent dislocation is high in this age group. The most important static stabilizer for lateral patellar dislocation is the medial patellofemoral ligament (MPFL). The injury to the MPFL and the anatomic patellar instability risk factors for lateral patellar dislocation are best described in the adult population. There is no consensus about the best treatment for the first-time traumatic lateral patellar dislocation in children.

The aim of this thesis was firstly to describe the current spectrum of acute knee injuries presenting with knee hemarthrosis, with a detailed description of the most common injury, the traumatic lateral patellar dislocation. Secondly, the aim was to describe the patellofemoral joint morphology, the anatomic patellar instability risk factors and the medial patellofemoral ligament injury in the skeletally immature child. Thirdly, the aim was to evaluate if an acute refixation of the medial patellofemoral ligament injury vs. non-operative treatment for first-time traumatic lateral patellar dislocation could reduce the high recurrence rate.

All studies were prospective in design. Patients were skeletally immature, 9-14 years old, and previously had healthy knees before an acute knee trauma that caused hemarthrosis. They were following an algorithm to investigate the injury with standardized radiographs and MRI within two weeks from the index injury.

In **Study I**, 117 patients with acute knee trauma were examined. Seventy percent had a serious knee injury that needed specific medical care. Fifty-six percent of these patients had no visible injury on their radiographs. Lateral patellar dislocation (41%), ACL injury (12%) and anterior tibial spine injury (7%) were the most common injuries and the majority were sports-related. **Study II** included 74 patients with first-time traumatic LPD. The medial patellofemoral injury was evaluated by MRI and arthroscopy. An injury to the MPFL at the patellar attachment site was diagnosed in 99% of patients, either as an isolated injury at the patellar site or as part of a multi-focal injury. **Study III** consisted of 103 patients with first-time traumatic LPD and a control group of 69 patients with acute knee trauma without LPD. The morphology of the patellofemoral joint and anatomic patellar instability risk factors were analyzed and the two groups were compared. Central condylar height was higher in the group with lateral patellar dislocation, resulting in lower trochlear depth and higher sulcus angles. There was a significant difference in mean values of all established anatomic patellar instability risk factors between children with first-time traumatic LPD and the control group. The main divergent anatomic patellar instability risk factor was trochlear dysplasia (defined as trochlear depth < 3mm), which was seen in 74% in the LPD group compared to 4% in the control group. Trochlear dysplasia, together with lateral patellar tilt (≥ 20°), had the strongest association with LPD. The 74 patients from Study II were in **Study IV** randomized in a RCT to either non-operative treatment (soft knee brace and physiotherapy) or operative treatment (arthroscopic assisted medial patellofemoral ligament refixation, soft cast splint and physiotherapy). The follow-up time was two years; the main outcome was redislocation and evaluation of subjective and objective knee function. A refixation of the MPFL injury in the acute phase in skeletally immature children with first-time traumatic lateral patellar dislocation significantly reduced the redislocation rate but did not improve the subjective and objective knee function compared with non-operative treated patients. The majority of the patients were satisfied with their knee function.

LIST OF SCIENTIFIC PAPERS

This thesis is based on the following original articles and manuscript. Every paper will be referred to in the text by their corresponding Roman numerals.

I. **Askenberger M**, Ekström W, Finnbogason T, Janarv P-M. Occult Intra-articular Knee Injuries in Children with Hemarthrosis. The American Journal of Sports Medicine, Vol. 42, No. 7 2014. DOI: 10.1177/0363546514529639

II. **Askenberger M**, Arendt E. A, Ekström W, Voss U, Finnbogason T, Janarv P-M. Medial Patellofemoral Ligament Injuries in Children With First-Time Lateral Patellar Dislocations. The American Journal of Sports Medicine, Vol. 44, No. 1. 2016 DOI: 10.1177/0363546515611661

III. **Askenberger M**, Janarv P-M, Finnbogason T, Arendt E. A. Morphology and Anatomic Patellar Instability Risk Factors in First-Time Traumatic Lateral Patellar Dislocations. The American Journal of Sports Medicine, Vol. XX, No. X. 2016 DOI: 10.1177/0363546516663498

IV. **Askenberger M**, Ekström W, Bengtsson-Moström E, Arendt E. A, Hellsten A, Mikkelsen C, Janarv P-M. Operative Versus Non-Operative treatment of Acute First-Time Traumatic Lateral Patellar Dislocation in Children- A Prospective Randomized Study. Manuscript.

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LIST OF ABBREVIATIONS

ACL	Anterior Cruciate Ligament
APIF	Anatomic Patellar Instability Risk Factors
ATS	Anterior Tibial Spine
CCH	Central Condylar Height
CI	Confidence interval
CDI	Caton-Deschamps Index
GJH	Generalized Joint Hypermobility
EQ-5D-Y	EuroQoL-5 Dimensions –Youth
ICC	Intraclass Correlation Coefficient
ISI	Insall-Salvati Index
KOOS-Child	Knee injury and Osteoarthritis Outcome Score for Children
LCH	Lateral Condylar Height
LPD	Lateral Patellar Dislocation
LSI	Leg Symmetry Index
LTI	Lateral Trochlear Inclination
MML	Medial Meniscal Ligament
MCH	Medial Condylar Height
MPFL	Medial Patellofemoral Ligament
MPML	Medial Patellomeniscal Ligament
MPTL	Medial Patellotibial Ligament
MRI	Magnetic Resonance Imaging
Nm	Newton meter
NOT	Non-Operative Treatment
MT	Meniscal tear
OA	Osteoarthritis
OCL	Osteochondral Lesion
OR	Odds Ratio
OT	Operative Treatment
PCL	Posterior Cruciate Ligament
PF	Patellofemoral
PLC	Posterolateral Corner
PD	Proton Density
PRO	Patient Reported Outcome
PT	Patellar Tilt
QOL	Quality of Life
ROM	Range of Motion
SD	Standard Deviation
SPE	Sagittal Patellofemoral Engagement
S-H	Salter Harris classification
SPSS	Statistical Software Package
RCT	Randomized Controlled Trail
ROC	Receiver Operating Characteristic
TD	Trochlear Depth
TFA	Trochlear Facet Asymmetry
TSE	Turbo spin echo
TT-TG distance	Tibial Tubercle-Trochlear Groove distance
VAS	Visual Analogue Scale
VMO	Vastus Medialis Oblicus muscle

1 INTRODUCTION

It is natural for children to be physical active. To be able to participate in sports and recreational activities is essential for most children and provides major psychosocial, physical and health-related benefits. Knee injuries are often reported among children active in sports, however the literature is sparse about the incidence of injuries in the general population, especially the serious intra-articular knee injuries.

There is presently a dichotomy in the activity level of children in our society. There are more children that are physical inactive and overweight; there are also children that receive very intense specialized training during their early years. These circumstances may have affected the injury spectrum. In the adult population, the ACL injury is the most common intraarticular knee injury. In 1993 Vähäsarja performed an arthroscopic study of acute knee trauma in children and reported that lateral patellar dislocation was the most common injury and had a high incidence of associated osteochondral lesions.[171]

Lateral patellar dislocation is not a new phenomenon; there is a surgical method describing patella stabilization from the late 19th century, (i.e., the Roux-Goldthwait procedure).

The patellofemoral joint is biomechanically one of the most complex human articulations with different anatomical bone shapes, ligaments structures, and muscles. These structures alone or in combination, are responsible for patellar instability.

Over the years, clinical examinations, imaging, anatomical and biomechanical knowledge, have improved. The majority of studies of lateral patellar dislocations are performed on adult or mixed-age populations; and therefore, they have resulted in measurements and thresholds reliable only for those populations.

There is a peak in the incidence of first-time traumatic LPD among the young adolescents. The redislocation rate is especially high in the younger ages, with non-operative treatment resulting in redislocation rates of 30-70%. The other outcomes in the skeletally immature population such as subjective and objective knee function are sparse. Although treatment options are numerous, there is no consensus in how to best treat patients with a primary traumatic patellar dislocation. Additional knowledge regarding this area in the skeletally immature population is needed.

2 KNEE INJURIES

Knee injuries are common in the youth population; they represent the second most common injury after ankle injuries in the general population. The serious knee injuries are high represented in adolescent athletes.[29, 78]

In some sports, there is a higher incidence of knee injuries in female than males when compared by exposure time. Large epidemiology studies of knee injuries among adolescents have been performed in the United States and show that strains and sprains were the most common injuries followed by contusion and abrasions. Interpretation of these studies is challenging, due to the lack of standardized injury definitions and because the investigation of these injuries varies. [31, 57, 78, 96] Kraus et al.[88] described the epidemiology of knee injuries

defined by clinical examination and radiographs in children and reported extra-articular soft tissue injuries (83%) were the most common type of injury, followed by patella disorders

(4%), intra-articular knee injuries (3%) and fractures (1%). There are many studies describing sport-specific injuries in the international literature. Knee injuries are most common in the youth-population participating in basketball and soccer. The rising popularity and intensity of youth sports has increased the incidence of patellar dislocation. These sports-related injuries may be associated with significant morbidity in the pediatric population. [29, 54, 88] Treatment requires understanding of and attention to the unique challenges in the skeletally immature patient.

3 LATERAL PATELLAR DISLOCATION

The traumatic LPD is the most common knee injury in children presenting with hemarthrosis. This diagnosis should be distinguished from congenital or habitual patellar dislocations. The traumatic lateral patellar dislocation is equally distributed between the sexes with a peak incidence in the young adolescent period. Acute dislocation often occurs in active athletic children. The incidence in children age 9-15 years is 0.3-1.2/1000. The large span is probably due to different inclusion criteria used by the studies.[54, 122, 176] Redislocation rate with non-operative management varies widely with 30-70% being reported by different studies.[30, 32, 59, 99, 135] Each additional dislocation can significantly increase the chance of further recurrences.[54] In the long run, patellar dislocations can result in patellar instability, pain, decreased level of sporting activity, reduced quality of life (QoL), and patellofemoral osteoarthritis.[115, 158]

Patellar dislocation is predominantly lateral in direction due to the obliquity of the femur in humans. Medial or multidirectional instability are rare; thus, traumatic LPD is discussed in the following sections.

3.1 ANATOMY

During childhood, there is a natural development of size and maturation of the knee joints. The injuries to the knee joint are related to the bone maturity. When evaluating risk factors for lateral patellar dislocation, the skeletal maturity, and not just the age of the patient, needs to be considered.

During the 6-8th week of gestation the knee joint develops.[58] Formation of the subcondral bone plate and the hyaline articular cartilage occurs in the end stage of the development of the epiphysis, but the maturation of the cartilage continues throughout childhood. The patella develops deep to the patellar tendon as an uncalcified cartilaginous anlage; it continuous to grow and begins to ossify between 4-6 years of age. Alignment of the lower extremities is age-dependent in children and changes over time. As the child grows the femoral anteversion decreases and it is accompanied by a decrease in internal hip rotation. [117, 143] Physes mediate the longitudinal growth of the axial skeleton, and are at risk for injuries during childhood, which can result in growth disturbance. During puberty, there is a growth spurt and the physeal closure occurs at approximately 14 and 16 years of age for girls and boys, respectively.[65, 66]

In 2005 Glard et al. conducted an anatomical study of the trochlear groove in human fetuses of varying ages. They found that the trochlear cartilaginous angles were stable throughout their series and very close to the angles measured in adults; there was no correlation with age. However, height and length of the trochlear strongly correlated with age. [61] The configuration and maturation of the osseous and cartilaginous femoral sulcus during different phases of growth in children have been studied with ultrasonography by Nietosvaara et al. The osseous angle was inversely related to the age of the child and was flat in the youngest children.

During growth, it gained depth and assumed the shape of the overlying articular cartilage by adolescence. The thickest cartilage, up to 8 mm, was seen on the lateral facet in small children; during growth, this difference gradually diminished. The cartilage became thinner on both sides of the sulcus; and by adolescence the cartilage, was thickest at the deepest point of the sulcus.[121] Recently published MRI studies have shown the development of patellofemoral morphology with advancing age; and as described above the cartilage got progressively thinner during skeletal maturation. [85, 45, 118]

3.1.1 The patellofemoral joint

The patella is efficient for the extensor mechanism of the knee joint and for a normal gait to be achieved. The patella is the largest sesamoid bone and articulates with the distal femur. It acts as a fulcrum to transmit large forces from the quadriceps muscle to the tibial tubercle at varying angles. There is a natural 6° valgus angle between the femur and the tibia in the coronal plane and a similar angle between the trochlear groove and the tibial tubercle; this leads to a lateral vector force with the quadriceps contraction acting lateral on patella.

The patella is dependent entirely on the soft tissues for lateral stability in full-knee extension. It enters the trochlear groove at approximately 20-30° of flexion and is stabilized within the bony trochlear walls during deeper flexion. Patellar and trochlear contact area shifts within the range of motion. The patellar contact area moves from inferior in extension and to proximal at 90° flexion; the trochlear contact area is from proximal to distal. When patella enters trochlea, the initial loading is on the medial cartilage, further on the largest contact is on the lateral facets, which bears 60% of the load due to their larger area. [6, 51, 81]

The patellofemoral joint is a complex human articulation where several different factors play important roles in the patellofemoral anatomy and the stabilization of the joint. These can be divided into three groups:

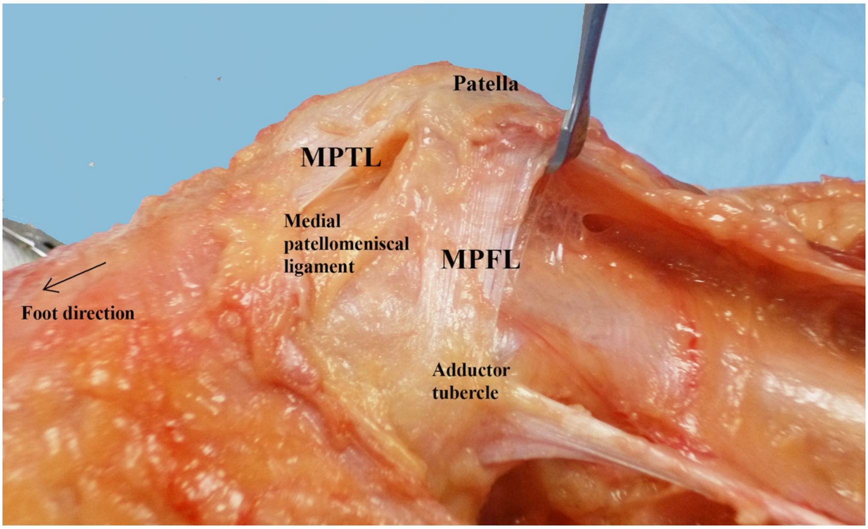
1) The bony structure, which includes the shape of the patellar and trochlear groove. The depth and the length of the trochlea matter for stability, but the slope of the lateral trochlear wall is the most important local factor in providing stability once the patella has reached the trochlea during flexion.

2) The soft tissue active (dynamic) stabilizer is the Quadriceps muscle: the rectus femoris muscle generates force by acting directly along the femoral axis. The oblique muscles, including vastus medialis and obliquus (VMO) and vastus lateralis, produce a transverse force vector. Together, these muscles generate an active, restraining force to stabilize the patella in axial, medial, and lateral directions.[50] The pelvic muscles contributes, and are also important for the stability and rotational alignment of the limb.

3) The soft tissue passive (static) stabilizers. These include the medial patellofemoral ligament (MPFL) which is the most important passive stabilizer. The MPFL acts as a static check rein to resist lateral translation of the patella; it guides the patella into the trochlea. The MPFL contributes up to 60% of the total restraining force against lateral patellar dislocation from extension to 30° of flexion. The medial retinaculum and the medial patellotibial ligament contribute with 3% each, the medial patellomeniscal ligament with 13% in early flexion but it is more important towards 90° of flexion against lateral shift, tilt and rotation. The lateral retinaculum has also a role and contributes with 10% of restraint to lateral patellar translation. [42, 142]

Injuries to these soft tissue structures engaging the patellofemoral (PF) joint, alternations in the configuration of the articulation, or muscular imbalance can affect the PF joint and lead to patellar instability.[10, 42, 74, 142]

3.1.2 MPFL



VMO was detached because it covered the main part of the MPFL.

Figure 1. Medial side structures of the knee.

The medial retinaculum consists of three layers; MPFL is placed in the second layer together with the medial patellotibial ligament (MPTL). The proximal superficial fibers of the MPFL interdigitates with the VMO muscle, and together they guide the patella towards the trochlea in early flexion.[7, 17]

The MPFL forms a triangle together with the MPTL and the medial patellomeniscal ligament. These ligaments together limit lateral and lateral superior translation.

MPFL originates from the patella's proximal medial 2/3, and attaches to the femur in the saddle between the medial epicondyle (proximal insertion of MCL) and the adductor tubercle.[170] Different studies have shown that the insertion of the MPFL on femur is distal to the femoral physis on average.[83, 90, 92, 119, 154].

The MPFL is thin, and has a mean tensile strength of 208N; the length in the adult population is approximately 5.5 cm.[116, 170] The MPFL is not isometric: it is taut when the knee is fully extended and slack in flexion when the patella is engaged in the trochlear groove. The length change pattern is most sensitive to the femoral attachment site. If the attachment site is proximal to the landmark on femur it leads to an increased distance to the patellar attachment as the knee flexes and become tight, with the opposite true for a more distal attachment.[7] A radiological landmark for surgical use for the anatomical insertion of the MPFL on the medial femur condyle is described by Schöttle et al.[151]

Table 1. Distribution of MPFL injuries (%) in Adults and Children Based on MRI studies.

Adults	Number	Age	Patellar	Midsubstance/ multi focal	Femoral
Kirsch et al., 1993	26	14-50	31	69	0
Virolainen et al., 1993	20	18-22	100	0	0
Courneya et al., 1994	20		60	0	85
Sally et al., 1996	27	14-46	4		87
Sanders et al., 2001	14	12-60	13		87
Nomura et al., 2002	27	13-29	0	59	37
Ellias et al., 2002	81	9-57	76	30	49
Sillanpää et al., 2008	46	19-22	20	23	57
Guerrero et al., 2009	195	mean age 23	47	13	26
Zhang et al., 2015	121	≥ 18	30	29	40
Children					
Zaidi et al., 2006	26	10-18	73	8	15
Kepler et al., 2011	44	10-18	61	21	12
Balcarek et al., 2011	22	10-15	10	50	40
Seeley et al., 2012	110	11-18	31	33	14
Zhang et al., 2016	140	9-17	37	28	30

Previous studies have shown that there is a high incidence of MPFL injuries (90%) in patients with a first-time, traumatic LPD, [14, 42, 83] which increases the risk of redislocation. The reported locations of MPFL injuries vary in the literature. The earliest reports investigating the adult population showed a high incidence of femoral-based lesions. More recent studies in the adult and aged-mixed populations have reported a variety of multifocal, central, or patellar attachment injuries; the majority of the lesions were at the patellar attachment site in the younger population. [47, 83, 140, 147, 157, 183] It is important to know the location and severity of the MPFL injury in the treatment decisions for traumatic LPD.

3.2 CLASSIFICATION OF PATELLAR INSTABILITY IN CHILDREN

In today´s literature, there are several different classifications and descriptions reported for patellar instability in children and adolescents. In order to understand the results of these studies in which patients with patellar dislocation received different treatments, it is important that the description of the included patient group(s) are consistent.

The nomenclature used when describing instability can be confusing. A recent article clarifying both nomenclature and classification has been published by Parikh et al. [136]

3.2.1 Terminology and description

Patellar subluxation is a partial lateral movement of the patella out of the trochlea; some articular contact between the patella and trochlea is retained (based on signs, symptoms or radiographs).
Patellar dislocation is a complete lateral movement of the patella out of the trochlea with no articular contact between them.
Patellar instability is patellar subluxation or dislocation.

First-time patellar dislocation is the first true episode of patellar dislocation wherein the deformity had to be reduced or self-reduced.

Recurrent patellar dislocation is a second or subsequent episode of patellar dislocation wherein the deformity had to be reduced or self-reduced.

Dislocation can also be classified by how it occurs. For *habitual dislocations*, the patella dislocates in every cycle of knee flexion and extension.[22, 37] There can also be *voluntary* or *fixed / permanent dislocated patellas.*

3.2.2 Etiology

A *congenital* intrauterine patellar dislocation is often associated with limb deformities. *Developmental* dislocation was not present at birth but develops after the child starts walking. *Syndromic* patellar dislocation is part of varying syndromes including connective tissue disorders and dislocations associated with neuromuscular disorders.

Atraumatic LPD occurs with minimal trauma due to an activity that is part of daily living. It is more common in pre-pubescent children. [67] The most common pathoanatomies in this group are patellar alta, trochlear dysplasia, joint hypermobility and congenital valgus deformity.[19, 124]

Traumatic LPD is often a noncontact injury resulting from a rotational force to the knee: a valgus/ abduction moment about the knee combined with an internal rotation of the femur and/ or external rotation of the tibia. These mechanisms are similar to those that leads to an ACL injury. The traumatic LPD can also be caused by a direct hit to the knee or as a result of a blunt trauma that causes a valgus/external rotation moment about the knee. This mechanism of patellar dislocation is the most common in adolescents, and it can occur in patients with a normal anatomy.[37] Potential pathoanatomies underlying traumatic lateral patellar dislocations are more recently studied. Patients with a first-time traumatic lateral patellar dislocation were studied in this thesis**.**

3.3 CLINICAL EVALUATION - INCLUDING HISTORY OF RISK FACTORS

It is necessary to understand the complexity of the patellofemoral joint in the treatment of patellar dislocations. The clinical and imaging evaluations of the patient are important. Anatomic patellar instability risk factors, the anatomical structures involved and general risk factors needs to be considered in the clinical setting to provide information for decision of treatment and if possible risk calculation of redislocation.

3.3.1 Clinical assessment in the acute phase

To achieve a correct diagnosis from the acute examination of a child with a knee injury is well known to be difficult, as extensive tenderness, hemarthrosis and pain is present and the younger child also often fear the exam. Although the history of the traumatic event is important, the story is often unclear. The child is not always aware that the patella has been dislocated, because spontaneous relocation of the patella occurs in the majority of the patients.[91] The radiograph is a good first diagnostic tool to rule out fractures. In many places the diagnostic procedures in children ends after a plain radiograph without specific findings. Intra-articular knee injuries become common from 9 years of age, and are found in children with hemarthrosis despite a normal radiograph.[167, 171, 179] Further diagnostics is needed, preferable with MRI preceding arthroscopy as a diagnostic tool in order to choose right treatment.

3.3.1.1 Clinical examination for patellar instability

The knee examination includes assessing the knee range of motion, thigh hypotrophy, alignment of lower extremities, and assessment of the general risk factors, which include genu valgum, excessive femoral anteversion, increased tibial external torsion, and joint hypermobility (genu recurvatum), (Beighton score).

Many clinical tests to assess patellar instability have been described. These include:

Apprehension test: this is performed with the quadriceps muscle relaxed and the knee in 0-20° flexion. The examiner attempts to translate the patella laterally. The test is positive if the patient voices fear of the patella lateralization or tries to avoid it with forceful muscle contractions.
Patellar glide test: the knee is relaxed in 0-20° knee flexion and the patella is manually glided laterally or medially. The patella is divided into 4 quadrants. A lateral glide greater ≥3 quadrants represents reduced medial patellar restraint. Excessive medial glide suggests reduced lateral restraint.
Patellar tilt: the knee is relaxed in 0-20° flexion and the examiner tries to flip the lateral edge of the patella upwards (i.e., the patella is tilted lateral due tight lateral retinaculum). Elevation less than to neutral is suggested to be an abnormal result.
Patellar tracking with quadriceps activated: a *positive J-sign* is when the patient raises the leg in to full extension and the patella suddenly shifts lateral in terminal extension converting an inverted J-sign. This may suggest a tight lateral retinaculum or a trochlear dysplasia. *The Q-angle:* is an important historical measurement. The Q-angle is the reflection of the valgus vector of the quadriceps pull acting on the patella and indicates the medial or lateral insertion of the quadriceps mechanism. The Q-angle is formed between two lines; one from the anterior-superior iliaca spine to the center of the patella and the other from the center of the patella to the tibial tubercle. This is a controversial measurement and what is defined as normal values is debated. [25] The Q-angle has recently been measured in healthy children and the reliability was moderate to fair, which was one reason why the authors suggest the Q-angle should not be used for clinical decisions without further research justifying its use. [130] Instead the TT-TG distance measured on MRI can be used for children.

The sensitivity/specificity and reliability/validity of physical diagnostic tests for patellar instability are unclear and the utility of these tests is sometimes limited.[161] Despite these limitations, the physical examination of the patellofemoral joint is regarded as the cornerstone in the diagnosis of patellar instability and together with general risk factors they complement the imaging evaluation in clinical decision making.

3.3.2 Radiographs

The examination in the acute phase includes imaging in three planes (anteroposterior, lateral and patellar axial) which is necessary to detect skeletal injuries and abnormalities. A patellar axial view is important for evaluation of the patellofemoral joint (e.g., Merchant view).[73, 108] Small avulsion fragments by the medial patellar border, lateral patella tilt, lateral patella translation can all be signs of a lateral patellar dislocation. Sometimes, the small chondral part from an osteochondral injury can be seen as a small crescent in the knee joint. The true lateral view, which is most helpful to measure patella alta and classify trochlear dysplasia, is often difficult to get in the acute setting in children with a painful knee. Radiographs can also reveal joint effusion, which indicates that further investigation is needed.

The Wiberg classification for patellar shape was described in the 1940s.[56] In a type I patella, the medial and lateral patellar facets are similar in size and both facets are concave. In type II, the medial patellar facet is shorter than the lateral facet. In a type III patella, the medial facet is convex and much shorter than the lateral facet.

Type I Type II Type III

Figure 2. Wiberg classification of patella shape.

Brattstrom undertook in the 1960s the first large scale study of trochlear shape and also defined the Q-angle as a valgus angle formed by the ¨quadriceps resultant + patella + ligamentum patella".[26] Blumensaat was one of the first to recognize patella position and its relationship to patellar dislocation in the 1960s. The Insall-Salvati index (ISI) for patellar height was described in the 1970s.[73]

3.3.3 Computed tomography

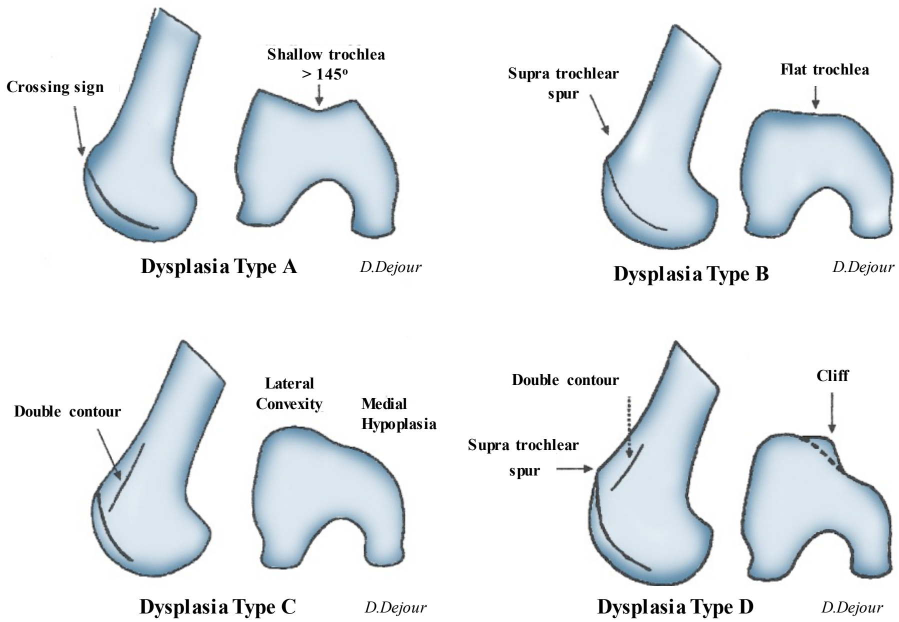
Computed tomography (CT) afforded the clinician with slice imaging of the patellofemoral articulation and has played an important historical role in developing imaging risk factors for patellar instability. It was used primarily to measure the tibial tubercle-to trochlear groove (TT-TG) distance, which was felt to be a more objective measure of the quadriceps angle compared to the 'Q-angle'. It was also used to measure lateral patellar tilt.

Dejour et al.[40, 41] stated, after analyzing true lateral radiographs and CT scans from patients with objective patellar instability and controls, that patellar instability had four principal etiological factors with statistically significant thresholds.

These four instability factors are:

Trochlear dysplasia
Patellar alta (i.e., Caton-Deschamps Index (CDI) ≥ 1.2)
Excessive TT-TG distance (≥ 20mm)
Excessive lateral Patellar tilt (> 20°)[41]

Trochlear dysplasia was first classified into three grades by H. Dejour, which has been further developed by D. Dejour to the four grades, and are widely used today. Figure 3.



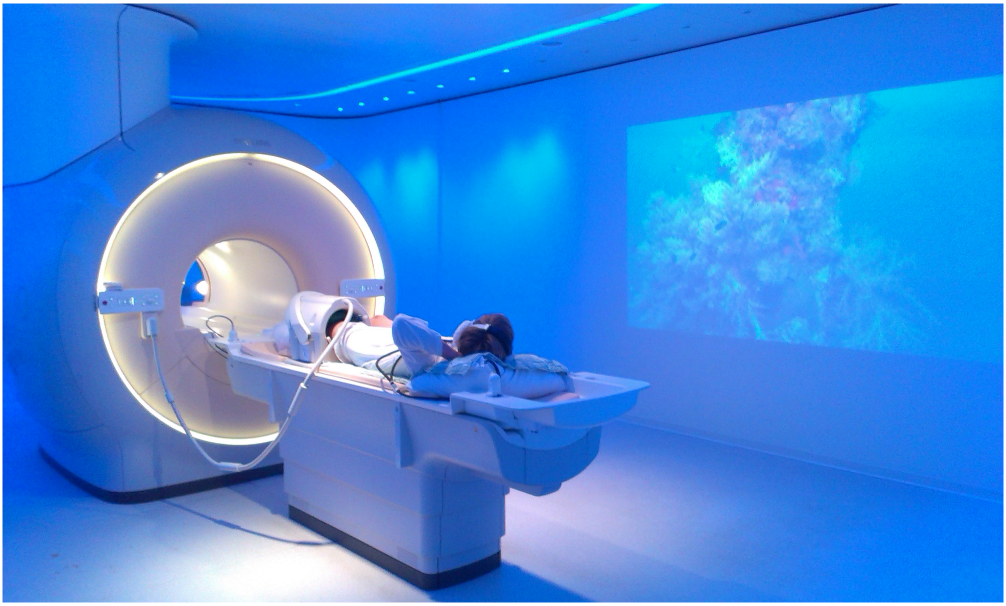
Permission to use from D. Dejour

Figure 3. Dejour Classification of Trochlear dysplasia.Type A, trochlear morphology is preserved with a fairly shallow trochlea; type B, flat or convex trochlea; type C, asymmetrical trochlear facets with a convex lateral facet and a hypoplastic medial facet; and type D, asymmetrical trochlear facets, a hypoplastic medial facet, and a cliff pattern.

In 1987, an algorithm for treating patellar instability according to these imaging instability factors was stated and coined by H. Dejour as ´le menu á la carte`. This surgical algorithm advised correction of each etiologic anatomical abnormality. [41] At this time, correction of a high grade trochlear dysplasia with deepening trochleoplasty was proposed.

In a study assessing the reliability of the Dejour trochlear dysplasia classification, Lippbacher et al., found that lateral radiographs tend to underestimate the severity of trochlear dysplasia compared with axial MRI read on the first craniocaudal image where complete trochlear cartilage can be seen. In addition, they found that the D. Dejour four grade analysis of trochlear dysplasia as described above had fair intra and inter observer agreements. The authors suggested a simpler two grade trochlear dysplasia classification: low grade dysplasia (Type A), and high grade dysplasia (Type B, C and D). Intra and inter observer agreements were found to have good to excellent agreement using this two grade system.[95]

The cartilaginous morphology has been shown to differ from the underlying bony morphology in patients with trochlear dysplasia. MRI is now essential in order to demonstrate the pathology and to facilitate surgical planning.[165, 172]



MRI examination

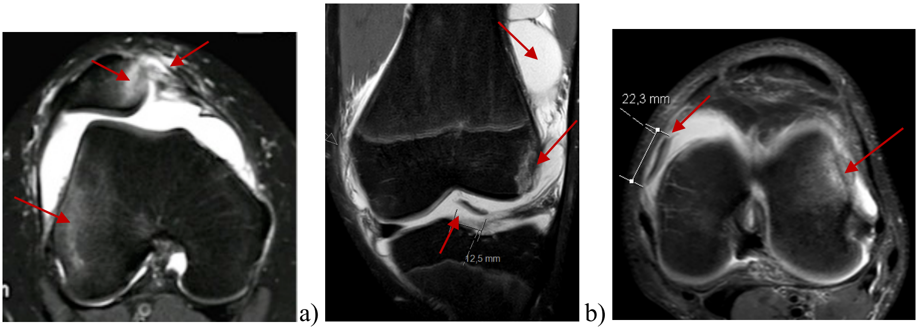
3.3.4 MRI

MRI is a preferable method for joint imaging. It is excellent in imaging cartilage, fibrocartilage, tendon, ligaments and to detect soft tissue and cartilage injuries as well as occult fractures. Some of the main advantages of MRI (beside lack of ionizing radiation) are the ability to detect subtle edema (the first sign of pathology) in soft tissues and bone marrow. The imaging knee protocols have improved as has the image interpretation; the sensitivity and specificity are considered good and the use of MRI is recommended in children.[86, 102, 134, 164, 179, 181] The disadvantage of MRI is that the patient has to lay still for an extended period of time, younger children might need sedation, because the survey takes approximately 20 minutes for a knee.

3.3.4.1 MRI specifics in lateral patellar dislocation

There are typical signs evident by MRI for traumatic lateral patellar dislocation due to the mechanism of the injury. When the patella laterally dislocates the medial structures are torn, specifically the MPFL, which results in hemarthrosis. When the patella dislocates and relocates, the medial patella strikes against the lateral femoral condyle, causing bone bruises, and sometimes cartilage injuries, which also contributes to the hemarthrosis.

Evidence by MRI of a lateral patellar dislocation includes hemarthrosis, MPFL injury defined as an edema at the injury site with or without disrupted fibers, a bone bruise pattern (edema) in the medial patella and/or a bone bruise pattern (edema) in the lateral femoral condyle with or without osteochondral/ cartilage lesions at the medial patellar facet/ridge or the lateral femoral condyle. [181]



a) b) c)

Figure 4. Typical signs of lateral patellar dislocation observed by MRI (proton density weighted imaging with fat saturation). (a) Axial view shows bone bruising (edema) on the medial patella and lateral femoral condyle, MPFL injury at the patellar site, and hemarthrosis (b) Coronal view shows osteochondral fragment, a lateral femoral bone bruise (edema), and hemarthrosis. (c) Axial view shows an osteochondral fragment, a lateral femoral bone bruise (edema) and a defect, and hemarthrosis.

The MPFL injury is classified according to the site of the injury; Type I patellar attachment site, Type II mid-substance injury, Type III femoral attachment site or Type IV multi-focal. [47, 83] Acute injury is defined by edema at the injury site. The manifestation of a partial MPFL tear includes discontinuity of some fibers, thickening and irregular fiber contour, and intraligamentous or extensive periligamentous edema. A complete tear manifests of the fibers in the expected region of the MPFL to be completely discontinuous, with extensive surrounding edema.[47, 182]

3.3.4.2 Anatomic patellar instability risk factors measured for treatment decisions

References used today are based on the adult population and the thresholds are made for patients with recurrent LPD and ‘objective’patellar instability in order to plan surgery. Older measurements are made on the bony contour based on radiographs or CT; more recently published MRI studies reports measurements based on the articular cartilage surface. A challenge when comparing study results are different definitions on how to measure and on which slice to make the measurements. The sulcus angle can, for example be measured where the sulcus is deepest, or 1 or 3 cm over the joint line, or at the first axial slice (going from cranial towards caudal) that shows cartilage covering the whole trochlea.

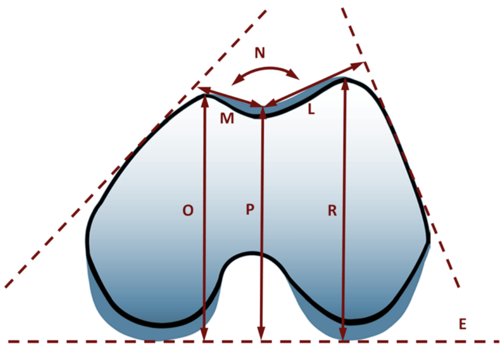
Pfirrman et al. showed that trochlear depth (<3mm) and the trochlear facet asymmetry (TFA) ratio <2:5 (medial divided by lateral <40%) had a sensitivity of 100% and specificity of 96% for trochlear dysplasia when measured 3cm above the femoral tibial joint line on MRI.[141] Carrillon et al. showed that a lateral trochlear inclination <11° is reliable for patellar instability, sensitivity 93% and specificity 87% measured on the first craniocaudal image that demonstrated full cartilaginous trochlear on MRI. Many different measurements are used; those most commonly reported in the literature are described in Figure 5 and the threshold for instability/ pathology used in the adult population are reported.

Trochlear dysplasia

Trochlear depth (mm) (TD) = ([O+R]÷2)-P
Average the lengths of the medial (O) and lateral (R) condylar heights, and subtract the length of the central condylar height (P).
Dysplasia is defined as < 3mm[141]

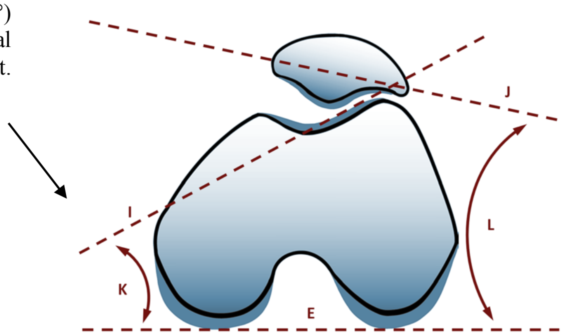
Sulcus angle (°) (SA) = N the angle between the medial (M) and lateral (L) trochlear facet.
Dysplasia is defined as > 145° [41]

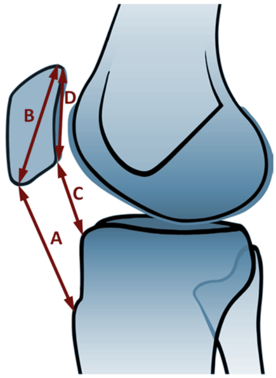
Trochlear facet asymmetry (%) (TFA) = M÷L x 100. The ratio of medial trochlear facet length (M) to lateral trochlear facet length (L).
Dysplasia is defined as < 40%[141]



Lateral trochlear inclination angle (LTI) (°) = K angel between (E) posterior femoral condyle and (I) a line across the lateral facet.
Instability is defined as < 11° [33]

Patellar tilt (°) PT = L the angle between posterior condyle (E) and line (J) at greatest patellar width (patellas midpoint).
Pathology is defined as ≥ 20° [41]



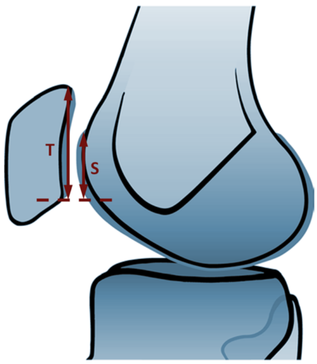


Patellar height

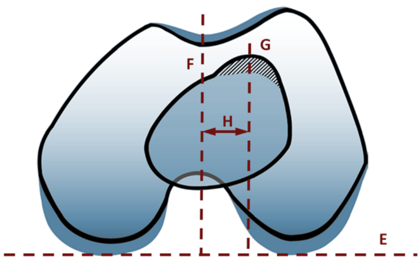
Insall Salvati index (ISI) = A÷B
Line (A) The length from the caudal aspect of the patella to the proximal insertion of the patellar tendon divided by line (B) the length of patella from cranial to caudal. Pathology is defined as > 1.3[112]

Caton-Deschamps Index (CDI) = C÷D
Line (C) from the distal part of the articular cartilage to the anterior corner of the superior tibial joint surface divided by the length of the cartilaginous articular surface (D). Pathology is defined as ≥ 1.2[41]

Patella ossification proceeds from proximal to distal; as the child matures the CDI decreases due to the enlargement of the patella on plain radiographs. CDI values in children ≥ 12 years of age were the same as adults when measured on radiographs in a recent published study [169] . Age-based values need to be considered when dealing with children < 12 years of age.



Patellotrochlear index (PTI) = S÷T Line (S) length of the trochlear cartilage overlapping the patellar cartilage divided by Line (T) length of the articular cartilage surface. Patellar alta is defined as <0.125[24]



Tibial tubercle- trochlear groove distance (mm) (TT-TG) = Measured distance H between lines (F) and (G). The axial view measure requires two slice imaging. Baseline (E) across posterior condyle, a line (F) at most inferior level of the trochlear groove perpendicular to the posterior line, super impost a second image of tibial tubercle; line (G) parallel to line (F) at the midline of patellar tendon insertion in to tibia. Pathology is defined as ≥20mm[41]

Figure 5. Anatomic patellar instability risk factors.

Bony template used with permission from E. Arendt, University of Minnesota.

The TT-TG distance measured on slice imaging, is the equivalent of the quadriceps vector by Q-angle measurement on physical exam. A TT-TG distance ≥ 20mm on CT scans has been found pathological for recurrent patella instability, and at risk for instability between 15-20 mm. TT-TG distance has shown to be a reliable measurement on MRI using cartilaginous and bony landmarks.[150] The TT-TG distance has recently been showed to vary as a function of patient height and age in children and adolescents. The TT-TG distance increases with 1.2 with each cm in height. Normalization of TT-TG distance to a patient's height may control for size.[139] Dickens et al. reported the TT-TG distance of healthy children without patellar instability. The median distance was 9.1 (±1.7) mm in children 9-10 years old and 9.3 (±0.6) mm in children 15-16 years old.[43]

These measurements have also been proposed to be used in the assessment for risk calculation for recurrence in patients after first-time lateral patellar dislocation. Balcarek et al. have suggested a patellar instability severity score (mean age of the study population was 19 years) which was based on six factors: age, bilateral instability, the severity of trochlear dysplasia (low- or high- grade), patellar alta, TT-TG distance and lateral patellar tilt. These factors were used to identify those who are most likely to redislocate.[15] They showed that young age (< 16 years), a severe trochlear dysplasia, and an excessive patellar tilt were significantly associated with an early episode of patellar redislocation.

3.4 TREATMENT

3.4.1 Historical treatment of recurrent patellar dislocation

Historical treatment methods used for recurrent patellar dislocation in children where aimed to correct extensor mechanism alignment. The *proximal realignment:* included vastus medialis advancement and medial reefing and were aimed to restore the soft tissue dysplasia and not primarily the medial restraint. This was often in combination with a lateral release to reduce a tight lateral retinaculum. The *distal realignment* in the skeletally immature was according to the Roux- Goldthwait procedure (medial transfer of the lateral patellar tendon) or the Elmsli- Trillat (medialization of the anterior tibial tubercle) in the child with closing physes. The distal realignment was performed when there was an increased Q-angle (>20°).[8 11]

The MPFL was recognized as an anatomic structure during the late 1970s, and later its important role in passive stabilization was determined. Knowledge of the anatomy and biomechanics of the MPFL has resulted in numerus methods using different grafts and attachment techniques, as well as arthroscopic repair of patellar site injuries and femoral reattachment procedures in the adult population. In the last decade, even methods suitable for children have been developed. The MPFL reconstruction approach has generally favorable outcomes regarding redislocation rate and patient reported outcome measures.[11, 53, 177] However, the MPFL reconstruction approach also has pitfalls and complications, and may alter the biomechanics resulting in pressure on the medial cartilage.[133, 137, 146]

3.4.2 Treatment of first time traumatic lateral patellar dislocation

There is a general agreement to use a non-operative treatment for patients with first-time patellar dislocation when no significant osteochondral injuries are present.[19, 84, 106] Since it is a common sports-related injury, and there is a high incidence of redislocation in the younger population, stabilization procedures have become more common even after the first event.[127]

3.4.2.1 Non-operative treatment

Non-operative treatment varies. Typically, it contains a short immobilization period, often transitioning to a knee brace, and early initiation of physiotherapy. Different regimes have been proposed in the literature such as immediate mobilization with no restriction, functional banding, specific bracing, knee brace or cast with the knee in extension for 4 weeks, followed by physiotherapy, but there is a lack of evaluation. Mäenpää et al. compared cast and splint for 6 weeks; the posterior splint group had the lowest proportions of knee joint restriction, the lowest redislocation rate and the fewest subjective complains at follow-up.[101]

Current physiotherapy is focused on strengthening of the quadriceps muscles and pelvic stabilizers, as well as core training to retain strength, stability and balance. It is also preferable to include home training programs and patient education. The goal before returning to sports activity, Physical education is to achieve: (1) no pain, (2) no effusion, (3) no patellofemoral instability, (4) a full range of motion, (5) nearly symmetrical strength (85-90 %), and (6) excellent dynamic stability.[107, 114]

There are few studies of physiotherapy interventions after patellar dislocation. A systemic review article by Smith et al. concluded that well-designed randomized controlled trials assessing different conservative management strategies with specific patient groups are required. A variety of different physiotherapy strategies have been reported, but the optimal strategy is not yet known.[160] To the best of my knowledge there is no available outcome studies for either type of immobilization, or efficacy of physiotherapy after patellar dislocation in childhood.

3.4.2.2 Operative treatment

There are few randomized controlled trials comparing non-operative management vs. operative treatment of first-time traumatic patellar dislocation in skeletally immature patients.

In a Cochran review by Smith et al., five randomized studies and one quasi-randomized study were reviewed evaluating surgical vs non-surgical treatment for first-time patellar dislocation. Four studies included children, but mainly adolescent and adults were included in the cohorts. The primary outcomes were frequency of recurrent dislocation, and validated patient-rated knee or physical function scores. The predominant surgery was repair or reconstruction of the medial soft tissue, in some cases also lateral release or Roux- Goldthwait procedure. Non-surgical management consisted of initial immobilization with cast, splint or locked orthosis, followed by physiotherapy. The minimum follow-up time was two years in the studies. The authors concluded that there is some evidence to support surgical over non-surgical management. They also concluded that the quality of the evidence was low due to the high risk of bias and the imprecision in the effect estimates. Additional adequately powered, randomized, multi-center controlled trials were recommended.[162]

In a review of first-time traumatic patellar dislocation, Stefancin et al. recommended initial non-operative management of a first-time traumatic dislocation except in several specific circumstances. The specific circumstances were the presence of an osteochondral fracture, substantial disruption of the medial patellar stabilizers, a laterally subluxated patella with normal alignment of the contralateral knee, or in patients not improving with appropriate rehabilitation. [166]

Nowaschu et al. recently presented a meta-analysis of surgical versus conservative management of acute dislocation in children and adolescents. Results were based on 11 studies. Conservatively treated patients were on average 17 years old with mean follow-up of 3.9 years. The surgically managed group had an average age of 16.1 years and follow-up of

4.7 years. The authors concluded that acute surgical treatment was associated with lower risk of recurrent dislocation and provided higher health related quality of life and sporting activity. However, surgical techniques were variable and included modified Roux-Goldthwait, MPFL repair, lateral release, and only one study of MPFL reconstruction. Further, the inclusion and the criteria for surgery varied, and no differentiation was made between skeletally immature and mature patients. This variability makes the results difficult to interpret and implement into clinical practice in the skeletally immature child. [127]

In a randomized clinical trial, non-operative treatment was compared with primary repair of the medial stabilizer combined with a lateral release or lateral release alone after acute patellar dislocation in children. Palmu et al. showed that both groups had high recurrent instability (71% and 67%, respectively) after 14 years follow-up, but both groups had satisfactory results in Kujala scores. [123]

Matic et al. presented in a systemic review the results of a Return to Activity After Medial Patellofemoral Repair or Reconstruction survey; inclusion criteria included acute or chronic patellar instability defined as dislocation or subluxation. The mean age of included patients was 22.1 (range 10-52) years, and the Tegner score was used for evaluation of a return to activity. They concluded that recurrent redislocation was higher in patients who underwent MPFL repair rather than MPFL reconstruction, the recurrence was 4 times more common in MPFL repair and 2.5 times more common in medial retinacular repair/ plication compared with MPFL reconstruction. However, repair and reconstruction patients had similar Tegner scores, so either method was successful in returning patients to their pre-injury activity level. [104]

3.4.2.3 Operative treatment for children with traumatic lateral patellar dislocation

Indications for surgery at present time include failure of non-operative treatment with recurrent episodes of LPD or acute LPD with osteochondral injuries. In order to determine which patient should benefit from which operation, clinical examination and anatomic imaging risk factors should be considered. When treating skeletally immature patients, damage to the physes must be avoided. The following are methods described in the current literature as options for the skeletally immature patients.

Refixation of the osteochondral fragment: Osteochondral fragments have good healing capacity after surgical intervention with resorbable pins, screw fixation and pull-out sutures in the skeletally immature population. A fragment >10mm in the weight bearing/ articular contact area should ideally be refixated with in 10 days from the index injury, but remains possible to refixate within two months with good healing results.[38, 60] If a patient is undergoing surgery for an osteochondral injury, an MPFL reconstruction might spare the patient recurrence and subsequent operations.

To restore static medial stabilizators: MPFL reconstruction can be done using one of several described methods. Reconstruction of the MPFL is showing promising results in children.[48, 94, 173] MPFL´s femoral insertion is distal but close to the femoral physes. If bony femoral attachment is to be used, care should be taken to avoid the physes. This can be accomplished by locating the femoral insertion by use of fluoroscopy (Schöttles point).[151] With care, growth arrest and proximalization of the femoral insertion while growing is avoided.[120] MPTL reconstruction in combination with MPFL reconstruction might improve current results.[69]

To correct patellar tilt: Lateral lengthening is preferable if possible since the lateral retinaculum also has a stabilizing function. This, in combination with MPFL reconstruction have lately been proposed. Lateral release should not be used alone, it should be additive to other procedures to re-center the patella or when objective lateral tilt by physical examination is present.[13]

For patellar alta and elevated TT-TG distance: Patellar tendon shortening,[8] patellar tendon transfer[98] and medialization of the patellar tendon with different methods for example modified Roux- Goldthwait procedure are options.[103] When the proximal tibial physes are closing bony procedures as Elmsli-Trillat: medial transfer of the anterior tibial tubercle and tuberositas tibia distalizing procedures are available; before physeal closure they can result in genu recurvatum.

Unfavorable alignment: Guided growth for genu valgum can be beneficial. The technique can be considered for patients if genu valgum of >10° and at least 12 month, but preferable 2 years of remaining growth.[62]
Trochlear dysplasia: Trochleoplasty, most physicians await physeal closer at skeletal maturity.

3.5 EVALUATION OF TREATMENT

To be able to evaluate treatment the inclusion criteria for each treatment must be consistent and the studies adequately powered.

Many studies have reported the success of treatment using the outcome variable of redislocation rate. Studies with subjective and objective knee function as well as long term outcomes concerning the cartilage health are sparse after first-time and recurrent patellar dislocation with index injury in the skeletally immature child. Treatment results reported and evaluated with Patient reported outcome (PRO) measurements are preferred measurement tools. The use of adult measures in children may lead to inaccurate evaluation and selection of treatments.[174] Therefore it is preferred that PRO measures used in children have been tested concerning validity and reliability for children.

Clinical outcome measures of physical function are usually based on muscle strength assessment[80] and on different performance tests, such as hop tests[4, 64, 75, 126] as muscle function may influence outcome and the risk of knee re-injury.[5, 27, 68] There is no single hop performance test that alone can evaluate function; a battery of different tests are preferred.[64]

3.5.1 Muscle strength and functional performance tests

Muscle strength performance can be challenging in the youngest ages due to the size of equipment used for example Biodex machines, and also the child's ability to interact. Isokinetic muscle strength has been studied among healthy children 7-12 years old and a significant and linear increase in strength was seen according to age, but no sex differences was seen up to age 11. There was a large variability within each age group, indicating that a normative sample of muscle strength measurements should include a wide range of values for each age group.[18, 35, 71]

A comparison of strength between uninjured and injured leg (leg symmetry index, LSI) can be used to compare individuals. In the general population, a LSI > 85% is considered normal.[18, 35] Before returning to high demanding pivoting sports an LSI > 90% is suggested.

Two recent publications evaluated functional test´s in children; the Single-limb mini squat test showed a moderate reliability.[130] Single-legged hop test and isokinetic muscle torque measurements were shown to be reliable methods for accessing knee function in sport-active children.[79]

3.5.2 PRO measurement

Patient reported outcome (PRO) measurement are used to evaluate the patient's own perception of the knee function and quality of life. A PRO measure can express clinical symptoms, activity limitations, and participation restrictions that the patient experience in their daily life. A PRO measure can be either generic or disease/ region specific.

Generic scores allow comparison across diagnoses, but are less responsive to specific conditions. An example is Euro QoL (EQ-5D) (adult version) and **EQ-5D-Youth version**[1, 144] which measure health related Quality of Life.

A disease specific score for knees is the **Kujala-score**,[89] a questionnaire to evaluate subjective symptoms and functional limits in patellofemoral disorders. Another knee specific score is the Knee injury osteoarthritis outcome score (KOOS) which is designed to assess joint injuries or degenerative diseases; this score has recently been further developed into a Swedish **child friendly version KOOS-Child.** [129, 131] Both KOOS-Child and the original KOOS scoring system utilize five subscales which are scored separately. These five subscales are Pain, Symptoms "knee problems", ADL, Sport/ play, and knee-related QoL. There are several more knee specific scores, but few are validated for children.[159, 161, 163]

Preferable activity measures should be included in the evaluation; however, no specific activity score has been developed for children. Thus, often used in the age-mixed population is the **Tegner activity score**.[168]

Knee-specific, general health, and activity level instruments are complementary and in combination provide a more complete assessment for patients with patellar dislocation.[138]

4 AIMS OF THE THESIS

The overall aim of this thesis is to increase knowledge of epidemiology of knee injuries in children with a special focus on the traumatic lateral patellar dislocation.

STUDY 1

To document the current injury spectrum of acute knee injuries with hemarthrosis in children.

STUDY II

To describe MPFL injuries in the skeletally immature patient with primary traumatic LPD by magnetic resonance imaging (MRI), and to compare the results with the injury found at arthroscopy.

STUDY III

To characterize the PF morphology and anatomic patellar instability risk factors through MRI measurements in skeletally immature children with and without a primary traumatic LPD and to identify (potential) distinctive differences between these two groups.

STUDY IV

To evaluate if arthroscopic assisted refixation of the MPFL in patients with acute first-time traumatic LPD would reduce the recurrence rate and give a better objective and subjective knee function compared with a non-operative treatment, using a prospective randomized study design. To report the association of anatomic patellar instability risk factors and redislocation rate.

5 METHODS

5.1 PARTICIPANTS AND DATA COLLECTION

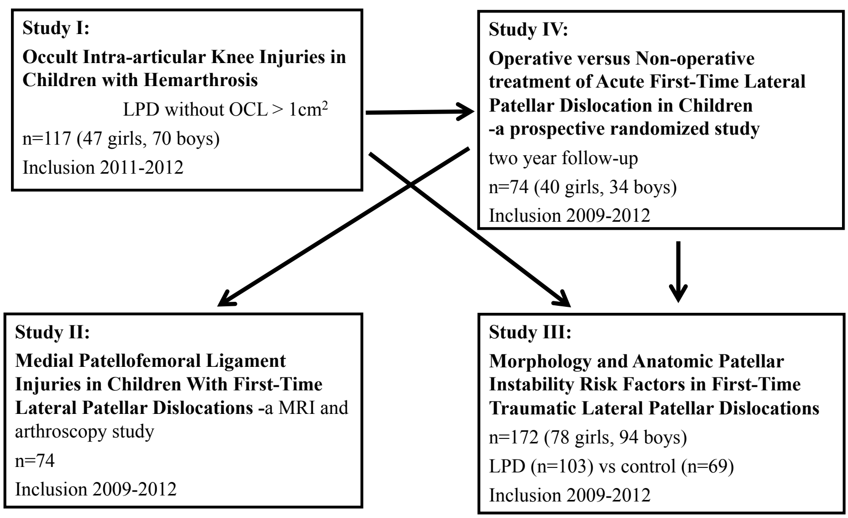
The four prospective studies in the present thesis include skeletally immature children 9-14 years of age and was conducted at Astrid Lindgren Children's Hospital at the Karolinska University Hospital in Solna, Stockholm. The hospital is responsible for pediatric orthopedic trauma care in a catchment area of 400, 000 children 0-14 years of age. When these studies were conducted, there were 132, 000 children 9-14 years old in this area. In Stockholm county, regional guidelines regarding pediatric knee injuries recommend that every child aged ≥ 9 years who is referred to a pediatric emergency unit with acute knee trauma followed by hemarthrosis undergo a clinical examination, radiography, and MRI to exclude serious intra-articular injuries. These circumstances explain the age limits in the present studies.

From December 2009 to April 2012, all children who came to the hospital and had a MRI-confirmed acute first-time traumatic LPD were asked to participate in these studies. Patients with lower limb disability or previous injuries to the affected knee were excluded in all four studies. Patients with an LPD with osteochondral injury (OCL) > 1cm^2 were excluded from studies II and IV.

From September 2011 to April 2012, all patients in Stockholm county with acute knee trauma with hemarthrosis were included in study I based on the above algorithm. Hemarthrosis was defined as an effusion in the knee joint within 12 hours after the acute injury. Patients with fractures involving the patella (horizontal and longitudinal) and the physes of the distal femur or the proximal tibia visible on plain radiographs were excluded (Salter-Harris [S-H] types I-V).[148] The patients from study I were also included in study III as patients with LPD or control patients without LPD. Patients with LPD without an OCL >1cm^2 were also asked to participate in studies II and IV.

All patients in these four studies had a clinical follow-up after the MRI, performed by a pediatric orthopedic surgeon who is experienced with knee injuries in children. The patient's history, clinical examination, and imaging findings were evaluated to diagnose the injury.

Figure 6. Linkage of the studies. All patients were 9-14 years old and skeletal immature



STUDY I

A prospective series of 117 patients with traumatic knee hemarthrosis; patients received clinical examination, radiographs at the emergency room, MRI and a follow-up within 2 weeks at the outpatient clinic. They were admitted for surgery when needed.

- The cause of injury, and participation in sports (type and frequency) were registered.
- The mechanism of injury was separated into four groups: spare time, sports, physical education, and traffic.
- Diagnoses were defined as serious or minor.

Serious injuries included: lateral patellar dislocation, total ruptures of ACL or PCL with or without associated injuries, anterior tibial spine (ATS) fractures, posterolateral corner injuries, meniscal tears, and intra-articular/ physeal fracture seen on MRI. The definition of serious injuries was based on the fact that these injuries will need special treatment and rehabilitation; delayed diagnosis might have severe consequences.

Minor injuries: MCL and LCL grade I sprains classified according to Hughston[72]; MCL grade I; injury involving a few fibers which resulting in an edema on MRI and palpable local tenderness, but no instability during a physical exam. Partial rupture of the popliteus tendon or adductor magnus tendon, minor partial tear of the ACL and unspecified edema in the knee capsule/soft tissue, or unspecified bone bruises in the distal femur or proximal tibia.

STUDIES II and IV

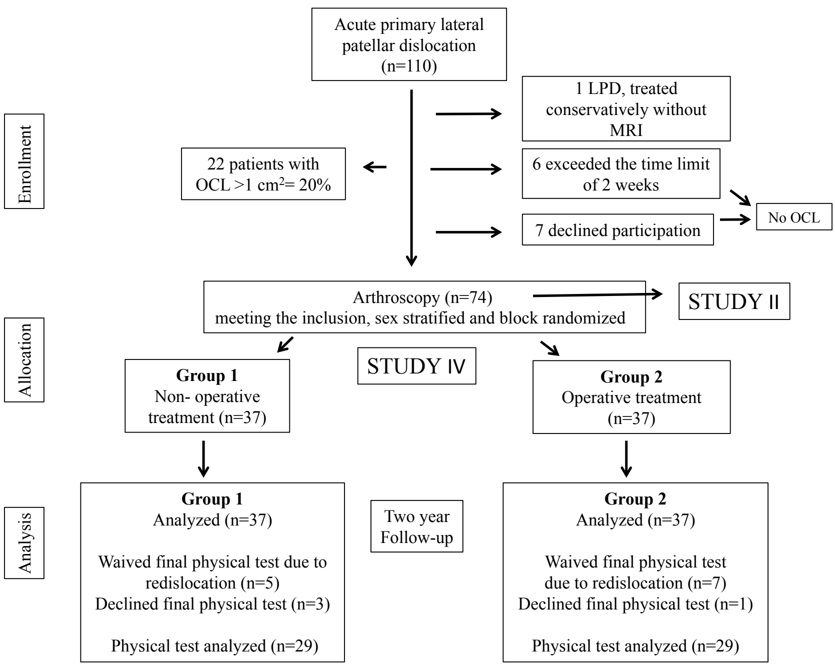


Figure 7. Flowchart of patients participating in studies II and IV. The same study group of 74 patients analyzed in study II were further randomized in study IV.

STUDY II

A prospective series of 74 patients with acute, first-time traumatic LPD in which primary clinical examinations, radiographs, MRI, and arthroscopic surgery were performed within 2 weeks from the index injury.

MRI classification of the medial patellofemoral ligament (MPFL) injury was divided into three different groups depending on the location of the injury with surrounding edema: patellar site, femoral site, or multifocal (including central injuries). Injuries were further divided into total (no visible intact fibers) or partial (remaining some intact fibers). Further description is provided in the MRI section.

Arthroscopic classification of an MPFL injury at the patellar attachment site was defined as a vertical rupture in the medial retinaculum at the patellar insertion, with or without a small avulsion fragment. The tear length along the vertical edge of the medial patellar border was measured in 5-mm increments from 0 to 4 cm with a meniscus hook. This provided an approximation of length rather than an exact measure of the injury size. An injury ≥2 cm in patellar length was defined as a complete avulsion of the MPFL.

Femoral attachment site injuries (extra articular) are not visible during arthroscopy; blood-tinged synovium seen towards the dorsal aspect of the medial femoral condyle was documented as an occult sign of an injury at the femoral attachment site.

STUDY III

A prospective series of 103 skeletally immature children aged 9-14 years with an MRI-confirmed acute first-time traumatic LPD were matched with a control group of 69 children (from study I). The control group consisted of patients with acute knee trauma with hemarthrosis that was not caused by a traumatic lateral patellar dislocation. The diagnoses are described in study I. Skeletal immaturity was defined based on radiographic observations of open or closing physes (the cartilaginous portions of the epiphyses become thinner). Closed physes was the definition for skeletal maturity.

With standardized MRI, the measurements for patellofemoral morphology and anatomical patellar instability risk factors were made on both bony and outermost cartilaginous points using sagittal and axial views. Methods used to measure them are described in the next MRI section; they are visualized in the introduction (MRI section).

To assess patellofemoral morphology: lateral, central and medial trochlear height, epicondylar width, trochlear angels and patellar length and patellar tendon were measured.

The following Anatomic Patellar Instability Risk Factors (APIF) were measured. *Trochlear dysplasia* was defined by: trochlear depth < 3mm,[141] sulcus angle ≥ 145°,[41] lateral trochlear inclination angle (LTI) <11°,[33] and medial/lateral trochlear facet asymmetry (TFA) < 40°.[141] Trochlear dysplasia was also assessed on MRI according to the Dejour classifaction,[41] Dejour type A-D are described in the introduction (MRI section).

Patellar tilt. Lateral patellar tilt ≥ 20°,[41] was considered pathological.
Tibial tubercle-to trochlear groove distance was calculated with 2 cutoffs: TT-TG ≥ 20 mm[41] (as defined by CT measurements) and TT-TG > 15 mm[150] (MRI threshold). *Patella alta* was defined as Caton-Deshamps index (CDI) ≥ 1.2[34, 41] or Insall Salvati index

(ISI) > 1.3.[73, 112] Sagittal patellofemoral engagement and Patellotrochlear index were also measured. Patellar shape was classified using axial imaging according to Wiberg.[56]

The four APIF groups were described with the following thresholds:

1. Trochlear dysplasia defined as Trochlear depth < 3 mm[41]
2. Abnormal lateral patellar tilt defined as Patellar tilt ≥ 20°[41]
3. Elevated TT-TG distance defined as TT-TG distance > 15mm[150]
4. Patella alta defined as CDI ≥ 1.2[41]

STUDY IV: Randomized control trail.

This was the same patient group as described in study II.

A second clinical examination was performed prior to the arthroscopy. Palpable pain at the patella's medial border and/ or at the femoral insertion of MPFL were noted. The APIF were documented as described in study III. The MPFL injuries were described as in study II.

The MPFL injury at the patellar attachment site was measured (i.e, 0-4 cm in length) as previous described in study II. Longer lesions included both MPFL and the medial patellotibial ligament (MPTL) attachment at the patella's inferior medial border. Diagnosis of a femoral attachment site injury that was treated was made using a combination of findings, including MRI (edema at the femoral insertion), clinical pre-operative examination (palpable pain at the femoral insertion of MPFL), and arthroscopy (blood-tinged synovium seen towards the dorsal aspect of the medial femoral condyle).

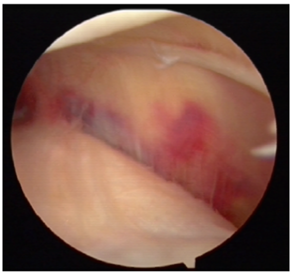
8a)  8b) 

Figure 8. Arthroscopy; a) patellar site injury and b) femoral site injury (blood-tinged synovium towards the medial femoral condyle).

Patients were randomized directly after the diagnostic arthroscopy with the patient still under general anesthesia. An envelope was prior prepared unknown for the surgeon with the randomization. Stratification was done for sex and the randomization was carried out with blocks of 6 patients.

Each child was randomized either to group;

1) Non-operative treatment (NOT) with orthosis; a lateral stabilizer soft knee brace (©2016 Breg) allowing full weight bearing used day and night for 4 weeks, and physiotherapy.

2) Operative treatment (OT); with arthroscopy assisted refixation of the MPFL with the use of anchors, followed by a soft cast splint allowing full weight bearing for 4weeks, and physiotherapy. Appendix A: home-training program and rehab program for OT. There are equivalent programs for the NOT groups but these are not attached.

The MPFL was re-fixated to the patellar attachment site and femoral attachment site with the use of Twinfix™- Ti 3.5 mm Suture Anchors (Smith & Nephew). The MPFL injury at the patellar site was refixated with arthroscopic visualization of the injury; a small skin incision was made at the medial side of the patella for anchor insertion. The femoral attachment injury was refixated with the same type of anchors through a small extra articular skin incision at the medial femur condyle.

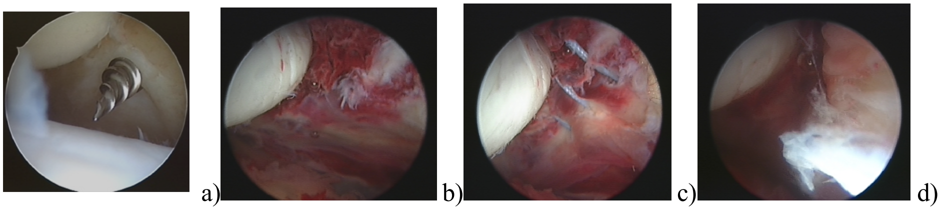


Figure 9. MPFL refixation with the use of Twinfix™- Ti suture anchors. a) Twinfix™ screw before insertion into the patella, pulling the MPFL towards patella; b) fresh injury; c) fresh injury with sutures shown before being tightened; d) refixated injury.

Twinfix™-Ti (2-4) was chosen due to the extent of the patellar-based injury when visualized in the arthroscope. Both the non-operative and the operative treated patients received a home training program, and they were referred to physiotherapists with specialized knowledge regarding PF rehabilitation of children. The rehabilitation program was focused on strength and functional training, including training of the gluteal muscles and CORE training for stability.

Post-operative follow-ups were performed after 1 month (surgically treated), and at 3 months (both groups). Appendix B

The final two year follow-up of both groups included:

1) Documentation of the main outcome (i.e., redislocation). Redislocation was reported at the time of occurrence during the two year time period.
2) Physical examination included: apprehenstion test, patellar tilt, thigh circumference, knee range of motion and Beighton score.
3) Subjective knee function assessed by PRO measure and activity score.
4) Objective knee function examined by Strength test and hop performance

5.1.1 Radiographs

All patients were examined with radiographs in 3 planes (anteroposterior, lateral and patellar axial view) of the knee.

Studies I-IV

An ATS fracture was classified according to Meyers and McKeever.[110, 111] Small avulsion fragments were noted. Occult signs for patellar dislocation (small avulsion fragment from the medial patellar border and displaced osteochondral fractures) were registered. The lateral view was evaluated for trochlear dysplasia according to Dejour; patellar height was measured with CDI and ISI, and the patellar shape was determined according to the Wiberg classification. [41, 56, 73] The radiographs were obtained in the first place to diagnose fractures that could be treated without further MRI evaluation, and these patients would not be included in the study. Joint effusion was documented.

5.1.2 MRI

All MRI examinations were performed at Astrid Lindgren Children's hospital on a 1.5-T Philips Achieva (Philips Medical Systems, Best, the Netherlands) with an 8-channel knee coil. The same knee coil and the following 5 sequences were used: transverse proton density (PD)–weighted turbo spin echo (TSE) with fat saturation, sagittal PD-weighted TSE with and without fat saturation, coronal T1-weighted TSE, and coronal PD weighted TSE with fat saturation. The slice thickness was 3 mm in all sequences. A single senior pediatric radiologist with extensive experience in musculoskeletal MRI reviewed all MRI examinations.

In study II, a second pediatric radiologist independently reviewed all of the MRI scans. Final interpretations were decided by consensus.

In study III, a second reader, a pediatric orthopedic surgeon, independently repeated the anatomic measurements and analyzed all other MRI parameters for 35 randomly selected participants (20 patients with LPD and 15 controls). Inter-observer reliability was assessed by calculating the intra-class correlation coefficient (ICC) for all analyzed parameters.

All Studies

The four major MRI signs for an acute LPD are (1) knee hemarthrosis with or without an osteochondral lesion (OCL), (2) an injury to the MPFL defined as edema at the injury site with or without visibly disrupted fibers, (3) a bone bruise pattern in the medial patella, and/or (4) a bone bruise pattern in the lateral femoral condyle. When the diagnosis was solely made based on the MRI signs, the patients had to have all four signs.

Study I
The physeal fracture seen on MRI were classified according to the S-H classification. [148] A posterolateral corner injury was defined as an avulsion of the femoral insertion of the popliteus tendon or in combination with an avulsion of the lateral collateral ligament (LCL).[175]

Study II
The MRI classification of the MPFL injury was divided into three different groups depending on the location of the injury with surrounding edema: patellar attachment site (edema was based at the patellar site), femoral attachment site (edema was based at the medial femur), and multifocal (edema was at ≥2 locations: ie., patellar, femoral, central, or diffuse edema along the ligament) (Figure 10).

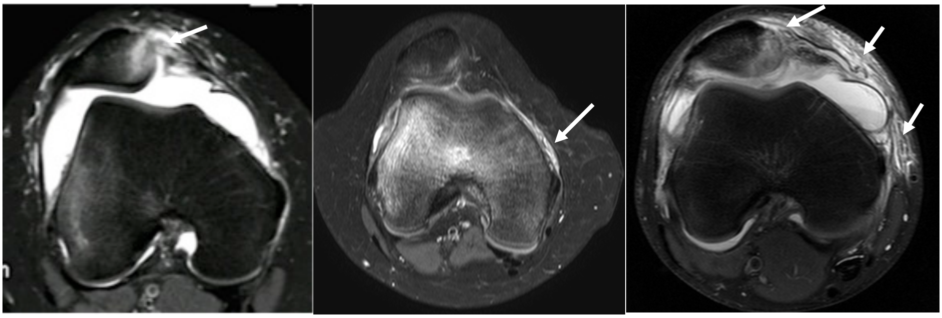


Figure 10a) patellar site, **b**) femoral site, **c**) multifocal MPFL injury

Study III

PF morphology and APIFs were assessed using sagittal and axial views. Distances and angles were measured on the bony and the outermost cartilaginous point to assess articulating joint geometry. [165]

Sagittal Measurements.

The sagittal slice showing the greatest length of the patella (through the central part of the patellar facet) was used for the sagittal measurements (Figure 11a).

Axial Measurements.

The first axial slice (going from cranial to caudal) that showed cartilage covering the whole trochlea was used for axial measurements regarding the trochlea and anterior aspect of the femoral condyles (Figure 11b). The axial slice that showed the most posterior aspect of the femoral condyles was used to define the posterior baseline and posterior landmarks of the condylar height measurements. An axial slice through the central part of the patella was used to measure the patellar tilt. A line through the bony midportion of the medial and lateral aspects of the patella was drawn, and the angle between this and the posterior baseline was measured. The TT-TG distance was measured using the same first axial slice; a line was drawn through the deepest point of the trochlear groove perpendicular to the posterior condyle tangent. The second line was drawn parallel to the trochlear line through the central part of the patellar tendon on its most proximal insertion on the tibial tubercle; the distance between the lines was measured.

Figure 11a) Measurements on sagittal view: Insall-Salvati index = b/a, Caton-Deschamps index = e/c, sagittal patellofemoral engagement = d, and patellotrochlear index = d/c. **11b**) Measurements on axial view: TD trochlear depth = ([a+c]/2) -b, and TFA trochlear facet asymmetry = e/f x 100. Lateral trochlear inclination was defined as the angle formed between the plane of the lateral trochlear facet and a tangential line through the posterior femoral condyle. Patellar tilt was defined as the angle formed between the line of the central patella and a tangential line through the posterior femoral condyle.

Study IV, MPFL injuries and APIF were measured and analyzed according to methods described for studies II and III.

5.2 EVALUATION

Study IV

5.2.1 Redislocation

Redislocation was reported continuously during the follow-up period with the final report at two year follow-up.

5.2.2 Physical examination

Test for patellar instability included: apprehension test, patellar tilt, patellar glide test, described in the introduction. (clinical examination) Thigh circumference (measured three cm above patella's proximal border), knee range of motion (ROM) was measured with goniometer, and Beighton score was recorded.

Beighton score [20]*:* is a score to measure joint hypermobility. It consists of nine variables; each receives one point if positive. Forward flexion of the trunk with knees full extended, palms and hands can rest flat on the floor, gives one point. The following four variables give one point for right and left, respectively: little (fifth) finger exhibits passive dorsiflexion beyond 90°, the thumb shows passive dorsiflexion to the flexor aspect of the forearm, the elbow hyperextends beyond 10°, and the knee hyperextends beyond 10°. There is no universal agreement for generalized joint hypermobility (GJH) rating among authors using Beighton Hypermobility Score. GJH was defined as present when ≥ four of nine tests are positive.

5.2.3 Subjective knee function

Subjective knee function was based on patient reported outcome (PRO) measures questionnaires for health related QoL, knee specific scores, and an activity score. The following section briefly describes salient features of each of these assessments.

EQ-5D-Youth [180]: is a generic questionnaire for health-related quality of life; it is a self-administered score applicable to a wide range of health conditions and treatments in children eight years and older. It contains two parts. The first is a descriptive system which comprises five dimensions: mobility, looking after myself, doing usual activities, having pain or discomfort and the last feeling worried, sad or unhappy. Each dimension has three levels: no problems, some problems, and a lot of problems. No overall score can be calculated, which means that all data are presented as the percentage of individuals reporting each level of problem for each item. The second part is the EQ visual analog scale; rating overall health from zero to 100. Zero indicates the worst health and 100 is the best health that can be imagined. The EQ-5D-Y has shown good psychometric properties when used in healthy children and children with various types of chronic health conditions. [144] (Appendix C)

KOOS-Child [129, 131]: is a self-administered, knee specific questionnaire recently developed to evaluate children 7-16 years old with knee disorders. It contains 39 items. There are five subscales that are scored separately: pain (8 items), symptoms "knee problems" (7 items), ADL (11 items), sport/ play (7 items); and knee-related QoL (6 items). Each question gives a score from zero to four, where zero indicates no problem. Raw scores are then transformed to a 0-100 scale, with zero presenting extreme knee problems and 100 representing no knee problems. A change of 2-3 points in group level and 15-23 points for an on individual is needed to detect a true change over time. A clinical significant difference is often considered to be 10 units, thus not yet specified for KOOS-Child. (Appendix D)

Kujala score [89]: is obtained using a questionnaire that evaluates subjective symptoms and functional limits in patients with patellofemoral disorders. It is commonly used in the adult population. It contains 13 items that assess: limp, mobility, aid dependency, walking, stairs, squatting, running, jumping, prolonged sitting with knee flexed, pain, swelling instability, thigh atrophy and flexion deficiency. Healthy individuals without patellofemoral conditions score a mean sum of 99.9 out of a total of 100 and lower scores are reported in patients with patellar instability and in patients with knee pain.[89] A Kujala score of 100 indicates no symptoms. A score of 95 or more is excellent, 85-94 is good, 65-84 is fair, and 64 or less is poor.[157] (Appendix E)

Physical activity levels were assessed according to the Tegner scale. [28, 168] The subject chooses which level of activity best describes their function and sporting participation. Levels range from 0 to10; a score between 0 to 4 covers activity in daily living. A score between 5 to 10 indicates that the subject participates in recreational or competitive sports. A score of zero denotes severe disability and 10 indicates an athlete that competes on national or international level. (Appendix F)

Visual analog scale (VAS) was used to assess pain in children. [155, 156] This requires the patient to select a point on a line representing the dimension of their pain intensity, where 0 present no pain and 10 worst possible pain. The pain scale has been extensively researched and show good sensitivity and validity for most children seven years of age and older.

5.2.4 Objective knee function

The performance-based functional test was preceded by a ten-minute warm-up on a stationary bicycle. Prior to the official test situation, the patients had practice trials on the dynamometer and tried the hop and squat tests to familiarize themselves with the testing procedure. Below, each performance-based functional test is briefly described.

For *concentric thigh muscle torque* assessment, a calibrated Biodex isokinetic dynamometer (Biodex Corporation, Shirley, New York, USA) was used. Concentric thigh muscle torque was defined as the peak torque at a single maximal voluntary contraction. Angular velocities of 90°/s and 240°/s were chosen for the trials; the ROM was set to 10–90°. The concentric knee extension and flexion were measured separately. Five maximal trials were performed for each test with velocity of 90°/s, and 10 maximal trials were performed with a velocity of 240°/s, with the highest peak torque in each test selected for further analysis. Thigh muscle performance was expressed as peak torque. Both legs were tested, and the uninjured leg served as a control. The leg symmetry index (LSI) for muscle performance was analyzed. LSI > 85% is considered normal.[35, 132]

Three single leg performance tests were included, and both legs were tested.

One legged hop test for distance.[126] The subject stood on one leg, and was asked to hop as long as possible, landing and balancing. The distance measured by a tape measurer fixed to the floor. The distance was measured (in cm) from toe in the starting position to the heel in the landing position. The best of three hops was recorded; if the subject improved more than 10 cm between the second and third hop, an additional hop was performed

An 85% limb symmetry score (15% difference between limbs) has been determined to be satisfactory for one-legged hop tests in the normal population.[18]

Side hop test. [75] Subjects stood on the test leg, and jumped from side to side between two parallel strips of tape, placed 30 cm apart on the floor. Subjects were instructed to jump as many times as possible during a period of 30 s. The number of successful jumps performed, without touching the tape, was recorded.

Single limb, 30s mini-squat test [130] The subject stood on one leg with fingertip support for balance and to direct the hip to decrease the risk of rotation of hip and trunk. The foot was placed on a straight line taped on the floor with the big toe against a perpendicular line; this should form a”T”. Patients were instructed to perform as many knee flexions as possible (the quantity of the test) during 30 s, by flexing the knee until the subject could not see their foot and then return to extension. The quality aspect of the knee motion, the medio-lateral knee position, was visually observed during the knee bending. A positive outcome with the knee medial to the second toe of the foot was registered and subtracted from the total score of the knee´s bending. This test has been tested in children and described by the authors as a contribution to the available toolbox for evaluation of dynamic medio-lateral knee position in children. It was validated in the adult population earlier.[3, 27]

5.3 STATISTICAL METHODS AND DATA ANALYSIS

The statistical analyses were performed using SPSS version 20-23, and the level of significance was set at $p< 0.05$ in all studies.

Table 2. Overview of statistics used in studies I-IV

Statistical method	Study I	Study II	Study III	Study IV
Descriptive statistics	x	x	x	x
Mean ±SD	x	x	x	x
Median with 25 to 75 percentile				x
Number percentage	x	x	x	x
Shapiro-Wilk W test			x	x
Mann Whitney U-test				x
Indipendent sample t-test			x	x
Chi-square test			x	x
Univariable and multivariable regression analysis			x	x
Pearson correlation cofficient			x	x
Interobserver reliability (ICC)			x	
Receiver operating characteristic (ROC) curve			x	

Studies III and IV

To test if variables were normally distributed, the Shapiro- Wilk W test was used.

A nonparametric test, Mann-Whitney U test was used for data not normally distributed. An independent sample t-test was utilized to compare continuous variables between patients in the two groups; a Chi-square test was used to compare categorical variables between the groups.
Inter-observer reliability was measured by the ICC. A receiver operating characteristic (ROC) curve was used to determine the best discriminatory thresholds for the APIFs. Correlations were tested with the use of Pearson.

In study III, multivariable logistic regression analysis was performed to find the most reasonable model to describe the relationship between LPD and the four main APIF´s. Results were presented as odds ratios (ORs) and 95% Cls. In comparison between patients with LPD and controls, adjusted for age and sex, multiple regression analyses were used for all APIF measurements.

In study IV, univariable and multivariable logistic regression analyses were employed to examine the extent to which redislocation could be explained by APIFs.

Power Analyses were conducted to assess the efficient number of patients to include in study IV. The sample size calculation was based on earlier studies and their redislocation rate and clinical experience, for non-operative treated (30-70%)[135] and operative treated patients (10%). [98, 157] The sample size required to detect a reduction of the recurrence rate of 30% from 40 to 10% is 64 patients, 32 patients in each group calculated with use of a study power of 80% and a type-1 error (α) of 0.05.

To detect a significant difference of 10 units (SD± 15) in Kujala, KOOS-Child or EQ-5D-Y under the assumption of a two-sided type 1 error rate of 0.05 and a power of 80% at least 37 patients were needed in each group. To detect a difference of 20 units, 10 patients in each group were sufficient in each group.

5.4 ETHICAL CONSIDERATION

All studies were approved by the regional ethics board of Stockholm and conducted according to the Declaration of Helsinki. Participation was voluntarily. Oral and written information was given to all participants. Written consent for each child to participate was obtained from either a parent or legal guardian in all studies.

6 RESULTS

STUDY I

There were 70% serious knee injuries in the 117 children (47 girls and 70 boys; mean age 13.2 ±1.3 years) with knee trauma causing a hemarthrosis. The majority of the injuries (85%) occurred at 12-14 years of age. The sex distribution was almost equal for boys and girls except for the age 14, where twice as many injuries were observed in boys than in girls. Fifty-six percent of the serious injuries had no visible injury on the plain radiographs.

Table 3. Incidence of serious knee injuries in children 9-14 years of age

Catchment are 132 000			Incidence/ 1000	
Injuries	(n= 82)	Percent	9-14 years	12-14 years
Lateral patellar dislocation	48	41%	0.6	1.2
ACL injury	14	12%	0.2	0.4
ATS fracture	8	7%	0.1	0.2
PLC injury	4	3%	0.05	0.1
Fractures (MRI)	4	3%	0.05	0.08
PCL injury	2	2%	0.03	0.03
Medial meniscus	2	2%	0.03	0.03

Patellar dislocation was three times more common than ACL injuries in this age group of children from the general population.

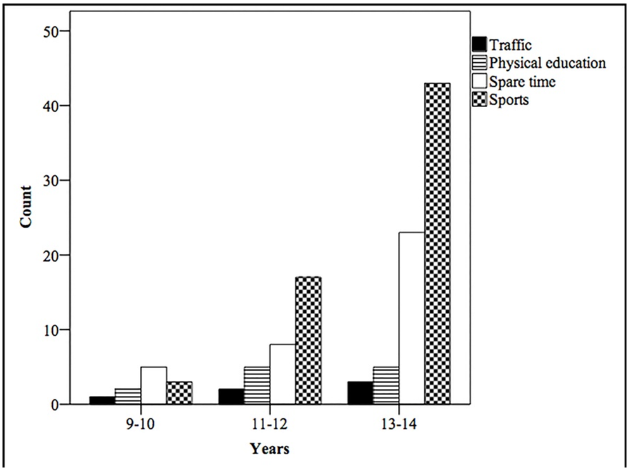


Figure 12. Cause of injuries in different age groups (n=117)

The injury occurred at organized sports or at a sports/athletic area in 54%, at spare time/playgrounds in 31%, during physical education in 10%, and 5% in traffic accidents.

Downhill skiing or snowboarding was the most dominant cause of injuries but did not represent the child's regular sports activity. The majority of these serious recreational activity caused injuries were avulsion type of fractures involving ACL (i.e., ATS fracture), PLC, PCL or MRI-identified physeal fractures.

Soccer and team handball were the most common organized sports that caused an injury and the majority of children practiced their sport ≥ 2 times/week, LPD and ACL injuries were the most common injuries.

The most common injury was the traumatic LPD and 52% occurred during sports activities. Twenty-five patients (52%) had no bony injury evident on their radiographs, 17 patients (35%) had an avulsion fragment at the medial border of patella and 6 patients (12%) had a dislocated osteochondral fragment. For 13 patients (27%) the patellar dislocation could not be discerned from the history, physical examination or radiographs. In those cases, MRI verified the injury.

STUDY II

Of the included 74 patients (40 girls and 34 boys; mean age, 13.1±1.1 years) with first time traumatic lateral patellar dislocation, 73 patients (99%) had an MPFL injury according to MRI or arthroscoy.

95%

%	MPFL	Patellar	Multifocal	Femoral	None
MRI	99	60	35	4	1
Arthroscopy	99	81	18		1

99%

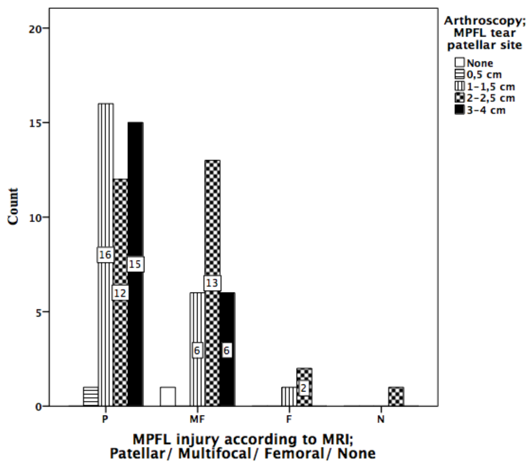


Figure 13. MRI and arthroscopy results (n=74)

MRI revealed a patella based injury in 95% and arthroscopy in 99% of the cases, either as an isolated injury or as part of a multifocal injury. MRI disclosed a multifocal injury in 26 cases (35%); 70% (18/26) were a patellar plus femoral site injury, 29% (7/26) patellar plus central. In one percent of cases, the whole MPFL was involved. The multifocal injuries at the central and femoral sites were evaluated as partial injuries. Arthroscopy showed the occult sign of a multifocal injury in 18 % of the cases.

Seventy-one percent of the total patellar site injuries identified by arthroscopy were correctly diagnosed as complete tears by MRI. Fifty percent of the partial MPFL tear at the patellar site diagnosed with MRI were misleading, as they were total ruptures when viewing the injury site in the arthroscope.

Patella attachment site edema on MRI was proved with arthroscopy to be a same site MPFL injury in 99% of the cases. Sixty-six percent of these patients had a total rupture at the patellar site confirmed by arthroscopy (≥ 2cm rupture). There were four arthroscopic MPFL lesions at the patellar attachment site not revealed by MRI, i.e., a false negative rate of 5%.

STUDY III

The 103 children with LPD (52 girls and 51 boys; mean age 13.1± 1.0 years) and 69 controls (26 girls and 43 boys; mean age 12.5±1.5 years), had an equal representation of open physes (85%) and closing physes (15%).

All established APIF´s used in the adult population showed significant difference between the LPD and control groups when comparing mean values (Table 4). More recent developed measurements for patella femoral engagement and patella-trochlear index were not significant.

Table 4. Patellofemoral Morphology Measurements.

	Control group (n=69)				LPD group (n=103)				
			95%CI				95% CI		
	Mean±	SD	lower	upper	Mean±	SD	lower	upper	*P Value*
TROCHLEAR CHARACTERISTICS									
Sulcus angle, cartilaginous, °	**141.1**	**6.7**	**139.5**	**142.7**	**156.7**	**8.8**	**155.0**	**158.4**	**<0.001**
Sulcus angle, bony, °	136.7	7.5	134.9	149.2	151.0	9.5	138.5	152.9	**<0.001**
Lateral condylar height, cartilaginous, mm	64.5	5.7	63.1	65.8	64.1	4.7	63.2	65.1	0.678
Central condylar height, cartilaginous, mm	58.7	5.3	57.4	59.9	60.6	4.7	59.7	61.6	**0.011**
Medial condylar height, cartilaginous, mm	61.9	5.2	60.6	63.1	61.8	4.6	60.9	62.7	0.943
Trochlear depth, cartilaginous, mm	**4.5**	**1.0**	**4.3**	**4.8**	**2.3**	**1.0**	**2.1**	**2.5**	**<0.001**
Trochlear depth, bony, mm	5.2	1.2	4.9	5.5	3.0	1.1	2.8	3.2	**<0.001**
Lateral trochlear facet, cartilaginous, mm	21.0	2.6	20.4	21.6	20.1	2.7	19.6	20.6	**0.035**
Medial trochlear facet, cartilaginous, mm	13.2	2.0	12.7	13.7	9.7	2.1	9.3	10.1	**<0.001**
Trochlear facet asymmetry, cart., %	**63.9**	**12.3**	**61.0**	**66.9**	**49.1**	**12.6**	**46.7**	**51.6**	**<0.001**
Lateral trochlear facet, bony, mm	21.6	2.7	21.0	22.2	21.8	2.8	21.3	22.4	0.618
Medial trochlear facet, bony, mm	14.4	2.1	13.9	14.9	11.2	3.7	10.5	11.9	**<0.001**
Trochlear facet asymmetry, bony, %	67.3	11.7	64.5	70.2	51.9	16.7	48.6	55.1	**<0.001**
Lateral trochlear inclination angle, cart., °	**20.9**	**3.5**	**20.1**	**21.8**	**13.8**	**5.4**	**12.7**	**14.9**	**<0.001**
Transepicondylar width, mm	79.2	6.4	77.6	80.7	78.1	6.2	76.9	79.3	0.278
Lateral condylar height, bony, mm	59.1	5.8	57.7	60.5	59.3	4.8	58.3	60.2	0.834
LCH, % of epicondylar width	74.7	5.5	73.4	76.0	76.0	4.7	75.1	76.9	0.101
Central condylar height, bony, mm	52.8	5.1	51.6	54.1	54.9	4.6	54.0	55.8	**0.006**
CCH, % of epicondylar width	66.8	4.9	65.6	68.0	70.5	4.8	69.5	71.4	**<0.001**
Medial condylar height, bony, mm	57.1	5.5	55.8	58.4	56.7	4.7	55.8	57.6	0.66
MCH, % of epicondylar width	72.1	4.8	71.0	73.3	72.7	4.7	71.8	73.6	0.417
PATELLAR CHARACTERISTICS									
Lateral patella displacement, mm	-0.5	2.3	-1.1	0.0	3.3	3.9	2.6	4.1	**<0.001**
Patellar tilt, °	**8.5**	**4.4**	**7.4**	**9.5**	**21.1**	**7.2**	**19.7**	**22.5**	**<0.001**
Patellar lenght, mm	41.5	4.1	40.6	42.6	40.2	3.6	39.4	40.9	**0.018**
Patellar tendon length, mm	45.4	6.7	43.8	47.0	51.5	6.2	50.3	52.7	**<0.001**
Insall Salvati Index	**1.10**	**0.17**	**1.06**	**1.14**	**1.29**	**0.18**	**1.26**	**1.32**	**<0.001**
Patella articular length, mm	30.6	2.8	29.9	31.2	30.5	2.9	30.0	31.1	0.933
Patellar tibia distance, mm	35.0	5.2	33.8	36.3	40.5	5.0	39.5	41.4	**<0.001**
Canton-Deschamps Index	**1.15**	**0.14**	**1.11**	**1.18**	**1.33**	**0.19**	**1.30**	**1.37**	**<0.001**
Sagittal patellofemoral Engagement, mm	16.1	5.4	14.8	17.4	15.7	4.7	14.8	16.7	0.682
Patellotrochlear index	0.53	0.18	0.48	0.57	0.52	0.15	0.49	0.55	0.654
TIBIAL TUBERCLE- TROCHLEAR GROOVE DISTANCE									
TT-TG distance, mm	**9.8**	**3.6**	**8.9**	**10.6**	**13.9±**	**4.7**	**13.0**	**14.8**	**<0.001**
TT-TG, % of epicondylar width	0.12	0.05	0.11	0.17	0.18±	0.06	0.14	0.19	**<0.001**

CCH= Central condylar height
LCH= Lateral condylar height
MCH= Medial condylar height
Bolding indicates significance and Anatomic patellar instability risk factors (APIF)

When analyzing the geometric components of the distal femur, there were no differences between the transepicondylar width or the lateral and medial condylar height (LCH and MCH, respectively) measurements. Central condylar height (CCH) was significantly higher in the LPD group with both bony and cartilaginous measurements. This correlated with a decreased trochlear depth and a higher sulcus angle. The mean trochlear depth was 2.3 mm in the LPD group and 4.5 mm in the control group.

Table 5. Anatomic patellar instability risk factors: sensitivity, specificity, OR and ROC curve results

APIFs	Control group (n=69)	LPD group (n=103)	Total	Sensitivity	Specificity	OR (95% Cl)	*P* Value
Patellar Tilt ≥ 20°						97.79	
<20	69	51	120	0.50	1	(exact OR)	**<0.001**
Pathology	0	52	52			(21.37-infinity)	
ROC curve= 15				0.81	0.93		
TT-TG > 15mm						5.40	
≤15	62	64	126	0.38	0.9	(21.37-12.97)	**<0.001**
Pathology	7	39	46				
ROC curve= 11				0.72	0.7		
TT-TG ≥ 20mm							
<20	69	92	161	0.11	1		**0.005**
Pathology	0	11	11				
Trochlear Depth < 3mm						61.93	
≥3mm	66	27	93	0.74	0.96	(17.96-213.47)	**<0.001**
Pathology	3	76	79				
ROC curve= 3				*0.75*	*0.96*		
Sulcus Angle, bony ≥ 145°						22.58	
<145	61	26	87	0.75	0.88	(9.55-53.40)	**<0.001**
Pathology	8	77	85				
ROC curve, bony= 143				*0.81*	*0.80*		
ROC curve, cartilaginous= 147				*0.85*	*0.81*		
Trochlear facet asymmetry < 40%						18.47	
≥40	68	81	149	0.21	0.99	(2.43-140.59)	**<0.001**
Pathology	1	22	23				
ROC curve= 54				0.71	0.78		
Lateral trochlear inclination ≤ 11°							
>11	69	68	137	0.34	1		**<0.001**
Pathology	0	35	35				
ROC curve= 18				0.77	0.78		
Caton-Deschamps index ≥ 1.2						5.50	
<1.2	44	25	69	0.76	0.64	(2.82-10.69)	**<0.001**
Pathology	25	78	103				
ROC curve= 1.22				*0.72*	*0.69*		
Insall Salvati index ≥ 1.3						5.38	
<1.3	60	57	117	0.45	0.87	(2.42-11.99)	**<0.001**
Pathology	9	46	55				
ROC curve= 1.18				0.71	0.75		

Bolded P values indicate statistically significant difference between groups in all measured APIFs. Italicized rows indicate values with consistency between the pathological thresholds used for adults and for skeletally immature children for trochlear depth, sulcus angle, and Caton-Deschamps index. LPD, lateral patellar dislocation; OR, odds ratio; ROC, receiver operating characteristic; TT-TG, tibial tubercle– trochlear groove.

ROC curves generated by our data show that there is consistency between the pathological thresholds used for adults and for our study population of skeletally immature children for trochlear depth, sulcus angle, and CDI. Specificity for patellar tilt, TT-TG distance, TFA, LTI, and ISI is high and close to one, but the sensitivity is lower. ROC curves show that the known pathological thresholds could be lower for patellar tilt, TT-TG distance, and ISI and higher for TFA and LTI in our cohort. There was no statistically significant difference between different ages in this age span when revealing the measured parameters on the outermost cartilaginous contour.

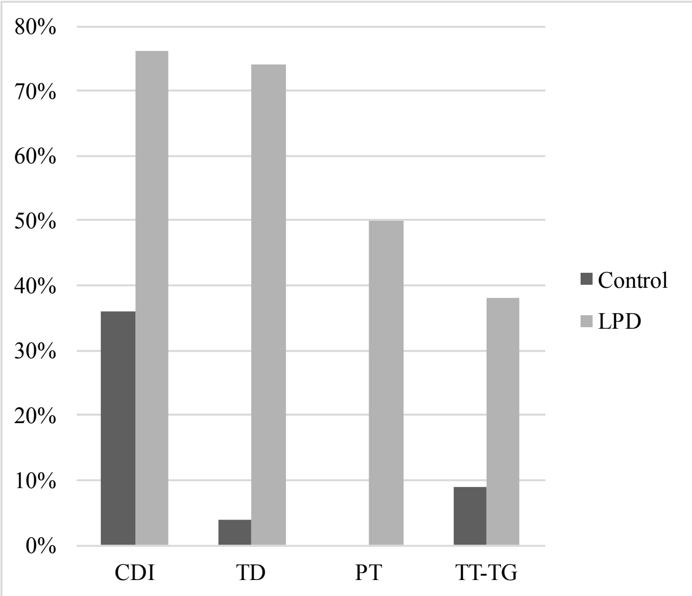


Figure 14. Frequency of each Anatomic patellar instability factor (APIF) by group

The main divergent APIF was trochlear depth (TD) 74% in the LPD group compared with 4% in the control group. Elevated TT-TG distance as a single APIF was never present in the LPD group; patellar tilt (PT) was only seen in the LPD group. The most common APIF in the control group was patella alta (CDI) (36%).

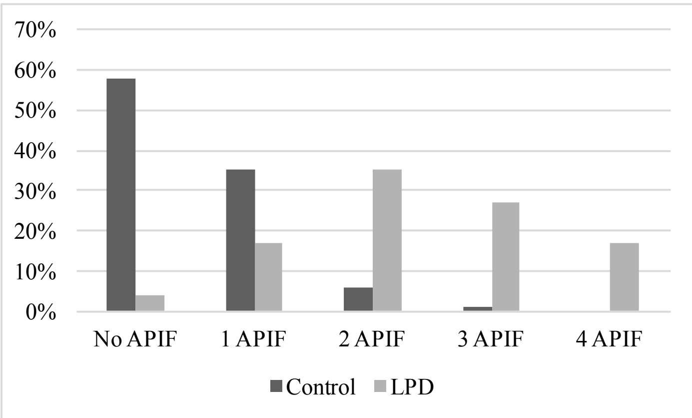


Figure 15. Frequency of 0 to 4 Anatomic patellar instability factors (APIF) by group.

In the LPD group, 79% had 2 to 4 APIFs compared with 7% in the control group. Different combinations of the 4 APIF revealed that trochlear depth < 3mm and patellar tilt > 20° displayed a very strong association with LPD.

STUDY IV

A total of 110 patients were admitted to the hospital with an acute, primary traumatic LPD during the study period. Seventy-four skeletally immature children, aged 9-14 years, fulfilled the criteria and accepted to participate in the RCT. (Table 6)

Table 6. Demographic characteristics at inclusion including anatomic patellar instability factors and the medial patellofemoral ligament injury. (n= 74)

	Group 1: Non- operative (n= 37)			**Group 2: Operative (n= 37)**			
Descriptives	n	Mean	SD	n	Mean	SD	P-value
Age at injury		13.03±	1.14		13.19±	1.08	n.s.
Sex, female; male	20:17			18:19			n.s.
Physes, open; closing	32:5			34:3			
Injured leg, right; left	17:20			19:18			
Injury during, contact; no-contact	17:20			15:22			
Anatomic patellar instability factors	%, (n)			%, (n)			
Sulcus angle cartilaginous (°)		156.20±	8.17		156.47±	9.43	n.s.
Trochler facet asymmetry (%)		48.75±	12.66		50.67±	13.31	n.s.
Lateral trochlear inclination angle (°)		13.87±	5.40		13.68±	5.82	n.s.
Trochlear dysplasia, TD< 3mm	**73% (27)**	**2.41±**	**0.94**	**73% (27)**	**2.3±**	**1.18**	**n.s**
Patellar tilt, ≥ 20°	**60% (22)**	**21.72±**	**6.66**	**46% (17)**	**21.86±**	**7.55**	**n.s.**
Elevated TT-TG distance, ≥ 15mm	**35% (13)**	**14.17±**	**4.41**	**35% (13)**	**13.34±**	**4.51**	**n.s.**
Patellar alta, CDI ≥ 1,2	**78% (29)**	**1.32±**	**0.17**	**78% (29)**	**1.39±**	**0.22**	**n.s.**
Insall Salvati Index		1.31±	0.17		1.29±	0.19	n.s.
Hypermobility							
Beighton score≥ 4	37% (14)	2.54±	2.95	35% (13)	3.05±	3.06	n.s.
Medial patellofemoral ligament injury		MRI	Arthroscopy		MRI	Arthroscopy	
P= Patellar		21	32		23	29	
M= Multifocal		13	4		13	8	
F= Femoral		2	1		1		
N= No injury		1					

Bolded are the four APIF groups

FOLLOW-UP AT TWO YEARS:

Redislocation

There was a significantly lower redislocation rate in the OT group (8 patients [21.6%]) at the two year follow-up compared with the NOT group (16 patients [43.2%]) (p=0.047). Among the patients with redislocation, the mean time from the first LPD to recurrence was 11.3 ± 6.2 months, in the NOT group 10.9± 6.7 months and in the OT group 13.1± 5.8 months. Redislocation occurred during sports activities in 75% and 25% were at spare time. Ten patients (13.5%) suffered a LPD on the contralateral knee during the study period.

Clinical examination

The apprehension test overall was negative in 89% of the patients, five patients in the NOT group and three patients in the OT group had positive signs.

Subjective knee function

The only significant differences between the treatment groups was found in KOOS-Child knee related QoL, with inferior values for the OT group (mean 62.7± 22.5) compared with the NOT group (mean 73.1±18.8, p=0.035). However, the significant difference was in the sub group of redislocaters. Patients with OT and redislocation had significant lower knee related QoL (mean 48.6± 11.9) compared to redislocaters with NOT (mean 68.1± 20.0, p=0.019), which lowered the total OT group score.

Kujala scores showed excellent outcome in NOT patients means (96) and good outcome in OT patients means (91).

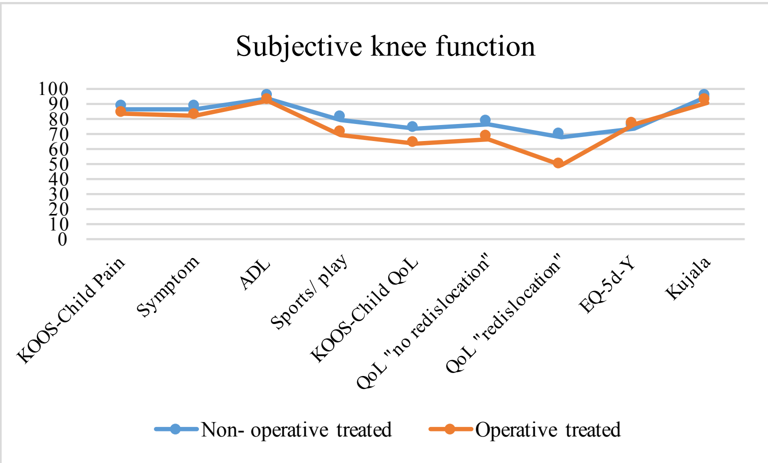


Figure 16. Mean values for Subjective knee function at two year follow-up. The first 7 scores are KOOS-Child; pain, symptoms, ADL, sports/play, QoL and sub-grouped QoL patients with no redislocation and with redislocation, followed by EQ-5d-Y and Kujala score. The rating in all three scores are from zero to 100.

Objective knee function

There were three statistical significant differences between the groups when measuring objective knee function. These differences indicated impairment in the OT group. The operative treated group had a lower number of side hops on the injured leg (p=0.04), reduced LSI for the single hop test (p=0.017) and a lower LSI for the isokinetic concentric Quadriceps torque 90°/s (p=0.048) when compared to non-operative treated patients.

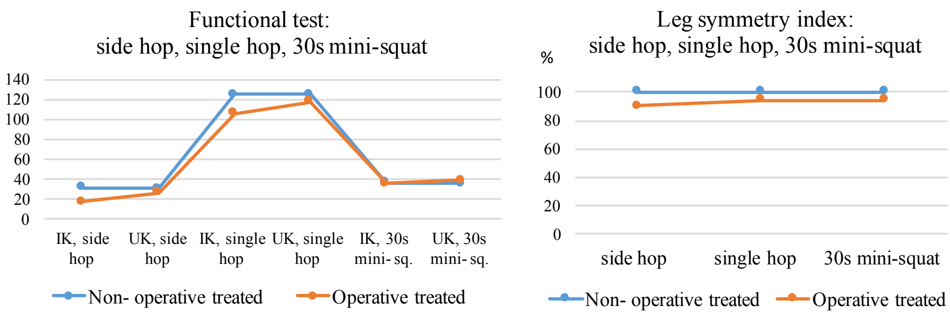


Figure 17. Median values for Functional tests. IK=Injured knee, UK= Uninjured knee, Side hop and 30s mini-squat is measured in numbers. Single hop is measured in centimeters. LSI= Leg symmetry index in (%).

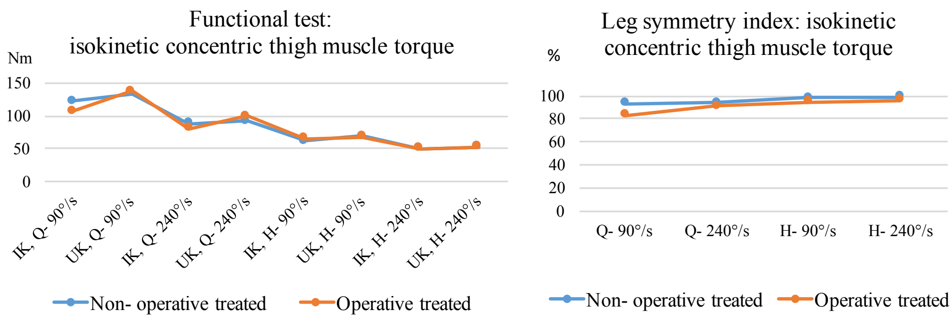


Figure 18. Median values for Functional tests. IK= Injured knee, UK= Uninjured knee, Q= Quadriceps muscles, H= Hamstrings muscles, LSI= Leg symmetry index in (%), Concentric speed= 90°/s or 240°/s. Unit of peak torque, Nm = Newton meter.

Results were similar except for the differences described above. Both groups had good results when comparing LSIs (with results over 90% for both hop and strength tests). Only OT treated patients had impaired results for LSI of the isokinetic Quadriceps muscle torque 90°/s (83%). Both groups had a reduction in their Tegner activity levels with one step at the two year follow-up; OT group mean was 4.5 and the NOT group mean was 4.9.

Anatomic patellar instability risk factors

In general, a large number of children with traumatic LPD had pathologic APIFs. There was no significant association between risk factors and redislocation. Due to the small sample size, the interactions between the treatment and risk factors were not analyzed. (Figure 19)

The OT and NOT groups were merged and the established (adult) thresholds for pathology were analyzed for the four groups of APIFs. There was no difference in proportion of pathological values between primary LPD, recurrent LPD and the patients with bilateral LPD when comparing patellar alta, lateral patellar tilt and elevated TT-TG distance. A higher percentage of trochlear dysplasia (trochlear depth <3mm) were seen in patients with redislocation (83.3%), and in those who suffered a contra-lateral LPD (90%) compared with the primary LPD group (73%). There was no significant difference between the groups of redislocaters and primary LPD in the number of APIFs present.

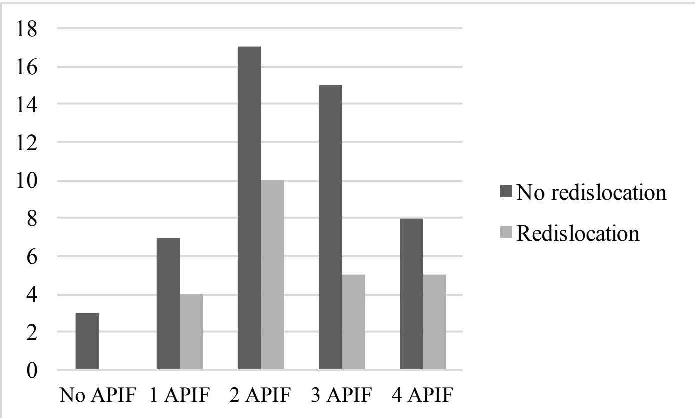


Figure 19. Number of APIFs present in patients with and without redislocation (n=74).

The four APIFs assessed with MRI: patellar alta = CDI >1.2, trochlear dysplasia = TD <3mm, Patellar tilt = PT <20° and elevated TT-TG distance >15mm.

7 DISCUSSION

Results in study I showed clearly that LPD is the most common serious knee injury in the skeletally immature patient.

These results support the conclusion of previous studies that MRI is an essential tool in this group of patients for confirming an accurate diagnosis. [2, 97, 179]

Seventy percent of the patients had a serious knee injury; and in more than 50% of the cases, clinical examination together with plain radiographs were not sufficient to confirm the diagnosis. Correct diagnosis is in turn crucial for achieving the best treatment.

Serious knee injuries were infrequent among the younger children, which has been shown in previous studies.[171, 179] The large majority of the injuries (85%) were seen in the age group 12-14 years and the sex distribution of injuries was equal in this group up to the age 13. There were twice as many boys with knee injuries in the age of 14 years; this large difference might partly be explained by the fact that girls leave organized competitive sports at this age. This trend has been described in national reports on children's participation in sports activities.[125]

Even in this unselected group of patients, the majority of the injuries were sports-related. Seventy-seven percent of the children were participating in organized sports one or several times a week. When looking at the type of sports activity, the current study showed that contact sports; soccer and team handball, were the most common sports to cause severe injuries. The most common injuries were LPD and ACL injuries, which is in accordance with previous studies.[23, 30, 96] Sports recreational activities; downhill skiing and snowboarding, caused mainly avulsion fracture-type injuries involving the ACL (i.e., ATS fracture), PLC, PCL, or MRI-identified fractures.

However, during spare time, accidently just twisting the leg, running, rustling for fun caused nearly 50% of the patellar dislocations. This could sound like an atraumatic patellar dislocation, but all patients included had a hemarthrosis.

In our study traffic-related injuries decreased compared to older studies, especially ATS fractures which used to be caused by bicycle/ traffic accidents. In the present study, ATS fractures were caused by skiing accidents (83%).[82] The number of patients is small, and it is not possible to make any far reaching conclusions, although traffic accidents involving children in Sweden have been reduced due to safety campaigns and environmental changes.[49, 70] At the same time, recreational skiing areas have become more advanced; the speed and energy have increased with carving techniques and fun parks, which might partially explain the high incidence of knee traumas related to this activity. The incidence of skiing-related adult injuries has declined due to rapid advances in technology, but the incidence of skiing-related trauma in children and adolescents remains high. The potential risk of trauma is compounded by inexperience, sometimes inadequate equipment, and musculoskeletal immaturity.[109]

One of the major findings is that the spectrum of injuries in our population of children differs from those in adults, where ACL and meniscus injuries are the most common followed by LPD. [39, 55, 128]

Our observed rate of ACL injuries (12%) was in accordance with Vähäsarja el al.[171] who reported a rate of 13%. In earlier arthroscopic studies, total ACL ruptures were present in 20% to 27% of patients.[23, 46, 164] Abbasi et al.[2] reported 22% complete or partial ACL tears in an MRI-based study of patients aged 10-14 years. However, the inclusion criteria differed between the studies, which makes it difficult to compare the results. The rate of associated meniscal injuries associated with the ACL injury was high: 64% in the present study.

Previous studies on acute ACL injuries have reported incidence rates between 21% and 60%.[44, 76, 105] Acute isolated meniscal tear in a morphologically normal meniscus was uncommon (2%) and in accordance with Vähasarja el al. and Wessel et al. results.[171, 178] Meniscal injuries have been shown to increase with age during adolescence.[97, 128] There are some divergent findings in the literature with higher incidence of meniscal injuries in MRI studies of children.[2, 97, 164] The interpretation of the MRI findings has improved. A persisting vascularization might mimic a lesion, and increased signal intensity (Grade I and II) is considered to be consistent with normal meniscus in children.[86 179] MRI findings must be correlated to the clinical examination and patient´s symptoms.

Isolated PLC injuries are rare.[175] Surprisingly, we found four patients (3%) during the study period. This might have been a random occurrence or because of an increased awareness of this type of injury or both of these possibilities.

The reported incidence for LPD in children has varied in previous studies from 0.3-1.1/ 1000 most likely dependent on different inclusion criteria and the age groups examined.[54, 122] We looked at knee injuries in the general population; and from our results we could see that LPD is the most common injury among children in organized sports as well as children who were in leisure time activities. An important observation is that the LPD in 27% of the patients could not be discerned from the history, physical examination, or radiographs; MRI verified the injury.

The cartilage injury measured on MRI is often larger in reality due to the fact that the slice thickness on MRI usually is 3mm. During the 2.5 year study period, patients with acute traumatic LPD and a cartilage lesions from articulated area > 1cm^2 were found in 20 % of the patients; this type of injury is preferably treated in the acute phase.[38] Seeley et al. showed that an MPFL injury was identified in 98% of the children with osteochondral fragments after LPD[153].

How is the MPFL injured?

In study II, a traumatic first-time LPD resulted in an injury to the MPFL in 99% of the patients. MPFL injuries according to MRI and arthroscopy were at the patellar attachment site in 99% of the cases and they were found either as an isolated injury at the patellar site or as part of a multifocal injury. In the acute phase, it is difficult to judge the severity of the MPFL injury by MRI unless it is a complete rupture. The injury is surrounded by an edema and it is sometimes difficult to completely visualize the fibers.

When comparing the results from MRI and arthroscopy; edema at the patellar attachment site that was evident by MRI was proven to be a patellar site injury by arthroscopy in 99% of the patients. The MPFL injury is in the majority of the cases a total rupture at the Patellar attachment site in children, though the severity of the injury varies and multifocal injuries exists. MRI and arthroscopy complement each other in order to get more detailed information of the MPFL injury.

A high incidence of MPFL injuries at the patellar attachment site in children and adolescents has also been described by Zaidi et al. and Kepler et al. using MRI imaging and with ultrasound and surgery by Felus and Kowalczyk. [52, 83, 181] In contrast to the findings of these authors, there are studies in which the incidence of patellar sited injuries in children and adolescents are close to one third or less.[16, 152, 184] Earlier studies in the adult or aged-mixed populations with relatively few patients included (n= 15-30) reported that > 75% were at the femoral attachment site.[147, 149] The latter have been with variable results of patellar attachment site injuries and multifocal and less femoral attachment site injuries.

There are remarkable differences between the study results concerning MPFL injuries. The inclusion criteria vary, the definition of the injuries and location site definition is variable, edema, partial, total ruptures are variable defined, total and partial ruptures are not separately reported. All of which makes it difficult to compare results.

However, it seems like skeletal maturity plays a role. The main studies in childhood are reporting the majority of the injuries at the patellar attachment side. Our study adds support to the literature; in skeletally immature children, the patellar site is the most frequent location of MPFL injury, either in isolation or as part of a multifocal injury. If the site of the injury influences the healing capacity in children is not yet known. It is important to get a detailed description of the MPFL injury as a first step towards a more customized treatment to optimize the outcomes in young patients with first-time LPDs. Improved nonsurgical treatment might be the best treatment for selected patients. If planning surgical treatment of the MPFL it´s important to know the individual's injury pattern for decision making.

Why do some patients sustain an LPD?

Multifactorial causation is assumed including developmental anatomical variations of the patellofemoral joint, which results in higher risk for LPD. These anatomical variances have been primarily studied in the adult and age-mixed populations, and most of these studies have focused on recurrent LPD.

In the adult population, how the MRI measurements are made, and which slice one uses to measure these anatomic factors have varied; an additional confounding feature is whether one measures on the bony structure or on the outermost cartilage surface. The measurement traditionally used in the adult population is distance, for example 3 cm above the joint line.[141] However, this is not a relevant measurement to use when comparing knees of a 9-year old and a 14-year old patient because femoral condyle size varies widely. When planning study IV, we realized that we had to standardize the measuring methods for MRI in the skeletally immature population. Describing the morphology and the anatomic instability risk factors in patients with first-time LPD compared with a control group to identify the potential differences in APIFs is the first step in identifying the potential differences between the normal, primary and recurrent patellar dislocation patient.

When analyzing the geometric components on the cartilage surface of the distal femur, the only difference was the central condylar height (CCH) which was higher in the LPD group. This resulted in a shallower trochlea; reduced trochlear depth and higher sulcus angle. This differs from results from adult studies in patients with "patellar instability". Biedert and Bachman showed two types of changes in patients with patellar instability; one group had abnormal lateral condylar height (LCH) with decreased lateral inclination of the lateral facet and the other group had decreased depth of the central and medial trochlear (CCH and MCH in proportion to condylar width was higher). [6] Charles et al. described lower MCH and CCH in the first cut of patients with patellar instability.[24, 36] The trochlear values reflect that a skeletally immature trochlea may not be the same as an adult trochlea or that our population with acute traumatic LPD, which did not contain the most severe high grade dysplasia types C and D, represents a subgroup of all patients with LPD (i.e., the traumatic LPD). Our experience is that children with severe PF dysplasia often experience dislocation without distinct hemarthrosis. Their diagnosis is usually elusive early on, with late clinical presentation as recurrent dislocations.

There was a significant difference in the means of all measurements between the control group and primary traumatic LPD patients when measuring established risk factors. The patellotrochlear index is a more recent method to measure patellar hight,[24] and no difference was found in our age group between controls and LPD patients for this measurement. An explanation could be that this measurement is relevant in more severe cases of patella alta and few of these types of cases were present in the traumatic LPD group. No age dependent differences were found in the measurements, although we have to make a reservation for few patients in the youngest ages 9-11 years. All anatomic instability factors established in the adult population that we analyzed are useful in the skeletally immature population, although some thresholds would benefit from revision using age appropriate data. Measurements are changing due to age, and skeletal maturity.[118] This said, adult thresholds for trochlear depth ≤ 3mm, Sulcus angle >145°, and CDI ≥1,2 are consistent between adults and our population of children according to our ROC curves.

Thresholds in risk assessment for recurrent LPD likely differ from thresholds for surgical intervention; larger cohorts are needed for appropriate decisions in thresholds values for surgical correction.

The four APIF groups; trochlear dysplasia measured as trochlear depth, patellar height measured as Caton-Dechamps Index, TT-TG distance and patellar tilt had good correlation with LPD and were used to make comparisons in studies III and IV. This group of patients with first-time traumatic LPD with hemarthrosis differs significantly from the control group in results of the four APIFs groups. The first-time traumatic LPD patient showed in general more pathological APIFs than have been described earlier,[12, 77, 87, 93] and this needs to be considered when making decisions regarding treatment. TD was the main divergent APIF. Patellar alta was the most common APIF in the control group, suggesting that patellar alta can be a normal variant in the knee and be well-tolerated when not in combination with other instability factors. Elevated TT-TG distance was never seen as a single APIF in the LPD group and patellar tilt was only seen in the LPD group. Hemarthrosis alone cannot account for the lateral patellar tilt in the LPD group. Excessive lateral patellar tilt is likely caused by an acute injury of the MPFL and/or lax medial restraint, combined with the anatomy of the PF joint in the LPD group.

It is well articulated in the literature that if the first LPD occurs in childhood, the risk of redislocation is high.[54] There are or have been several surgical treatments for recurrent patellar dislocations in children reducing the recurrence rate, although the few long term results detailing subjective knee function have revealed less satisfactory outcomes.[98, 115] In young patients with recurrent LPD treated primarily non-operatively, early degenerative cartilage changes have been seen in follow-up > 5 years.[21]

Could a minor arthroscopic assisted MPFL refixation after the first traumatic LPD make a change?

Study IV, is the first prospective RCT of skeletally immature children with first-time traumatic LPD comparing two-year results after arthroscopic-assisted refixation of the MPFL injury vs. non-operative treatment, including evaluation of both subjective and objective knee function. There are two important results. The redislocation rate was significant reduced, but still high (22%) with OT compared to NOT. However, this surgical method based only on the MPFL injury did not give better objective or subjective knee function compared to NOT. The second important result is that a large percentage of patients with NOT had good outcomes based on PRO measures, functional scores and 57% had no redislocation.

There are few RCT in childhood to compare with and even less if evaluation of objective and subjective outcome should be included. The follow-up period for our study was only two years which also makes it difficult to compare our results with studies that have longer term follow-ups. Palmu et al., with similar patient cohort (<16 years of age), showed a much higher redislocation rate after a 14-year follow-up when compared with the current study among both non-operative and operative treated patients, 71% and 67% respectively. The authors did a repair of the torn medial stabilizing soft-tissue structures diagnosed by arthroscopy; and in most cases, it was combined with a lateral release. No prior MRI was done. The longer follow-up time may partially explain the higher redislocation rate, although the majority of the patients experienced their first redislocation within two years of the primary dislocation. The Kujala score was equal in the non-operative and operative treated groups, 84 and 83, respectively, which is less than the present study NOT group 96, and OT group 91.

Both groups in study IV had good results in Kujala score, but patients in the OT group with redislocation had lower results in KOOS-Child QoL compared to NOT patients with redislocation. A slight impairment in the sport/ play subgroup of the KOOS-Child was found for the OT group, but this difference was not significant. The results from OT group in objective knee function tests were impaired in side hop on the injured knee, LSI for single hop test and LSI for isokinetic concentric Quadriceps torque 90°/s compared to NOT.

This differed in part with the conclusion in a systemic review on the management of acute patellar dislocation in children and adolescents (average age of 17.0 years in non-operative managed patients and 16.1 years in operative treated patients) by Nwachukwu et al.[127] Although the surgical technique used varied between the included studies, the authors concluded that operative treatment reduced the recurrence rate and operative treatment was associated with a higher quality of life and sporting function. Three of the included studies had an age span that matched our patients and their findings diverged in part from the above conclusion. Two studies reported reduced recurrence rates and one study reported no difference between the groups. Functional outcomes in the three studies were; good or excellent knee function in both group, no difference between the groups, or a non-significantly higher score for quality of life and sporting function in the surgical treated patients.[9, 115, 145]

Regarding the jump test evaluation; there are different abilities in the general population in physical performance and that has to be considered when making comparisons. We found a good correlation between high preinjury activity level and a good result in the side hop at the two year follow-up in general. There are no references values in the adolescent age for the general population; thus, ¨normal¨ is probably variable. Holm et al. described in healthy children 7-12 years of age a linear increase in strength, with a large variability within each age group, indicating that normative sample of muscle strength measurements includes a wide range of values for each age group.[71] A comparison between the uninjured and injured leg on an individual basis is more fair and described by leg symmetry index. In the general population, LSI > 85% is considered normal. [18, 27]

In the present study, a significant difference between the groups in the side hop on the injured knee was seen; the OT group was impaired, though the LSI for the side hop did not show a significant difference (NOT LSI = 100%, OT LSI = 94%, p = 0.2).

Even if there were a few statistical significant differences between the groups, the differences were small. An important fact is that the LSIs for hop and strength test for both groups showed good results (LSI > 90%). The exception was for LSI isokinetic concentric quadriceps torque 90°/s, with impaired result for the OT group (83%). LPD patients could in some manner be compared with ACL injury patients. In ACL injury patients, LSI observed during demanding tasks are associated with individual knee confidence.[4] The slightly lower results in some parameters could reflect the results of the KOOS-Child QoL.

For KOOS-Child scores, all five subgroups scores had significant correlations with the Kujala score. Kujala score showed an excellent outcome in the NOT group (96), and a good result for the OT-group (91). We cannot clarify the clinical importance of change over time, since they were all uninjured children when they entered the study. The only study that can be used for comparison is the one in which the KOOS-Child scoring was developed. The children participating were children seeking medical care due to knee symptoms, including both acute knee injuries, rehab patients and overuse injuries. Compared to that group both our OT and NOT groups had better outcome scores. Current there are no normal KOOS-Child reference values from a healthy child population that can be used for comparison. Moksnes et al. used KOOS at two year follow-up after non-operative treatment of children with ACL injuries and their results were very similar to our results of NOT LPD patients.[113] However, comparing results from KOOS-Child and KOOS scoring has not been validated.

There are several plausible explanations for the small differences between the groups. The surgical technique was not optimized as the re-attachment of the MPFL could lead to over-tightening and/or insufficient tissue integrity. The muscle function can also be an important factor; the majority of the children were approaching puberty with accelerated growth. This, in combination with surgery and loss of muscle strength during immobilization, as well as a lack of motivation (age-dependent), and possible insufficient rehabilitation could have resulted in weak muscles and reduced balance. These children were referred to physiotherapists with specialized knowledge regarding PF rehabilitation of children, but it was optional to choose any other physiotherapist. Although a uniform physical therapy protocol was used, quality of the therapy was not strictly controlled. Also, earlier studies have described extensor weakness in operated knees in long term follow-ups, which might indicate a permanent change in the musculature after injury and surgery. [63, 100, 115] As all patients had an injury and the surgery performed in this study was minor and the follow-up time was short, there are still opportunities for improvement. On the other hand, the NOT group did well, had good outcome scores (which can be the result of good rehabilitation), and the redislocation rate was less than reported in other age-matched studies.[93, 115, 135]

As previously described, the four APIFs were highly prevalent in this age group of skeletally immature patients with primary traumatic LPD. There was no significant association between risk factors and redislocation. Due to the small sample size, the interactions between the treatment and risk factors were not analyzed. Combining an MPFL repair at the same time as addressing APIF might have resulted in improved outcomes for the repair group; however, this question cannot be answered with the current study. Another alternative is to replace the injured MPFL with a MPFL reconstruction instead of a refixation, although the question for this study was if a minor surgery could make a change. It has been shown in a systemic review that recurrent dislocation was higher in patients who underwent MPFL repair compared with reconstruction, though the inclusions for the treatment options varied.[104] Lind et al.[94] reported that there were clinical relevant improvements in knee function and pain after MPFL reconstruction using soft tissue femoral graft in pediatric patients with recurrent LPD. The recurrence rate in this study of children that received MPFL reconstruction was equal (20%) compared with the OT group (MPFL refixation) in our study. Refixation of the MPFL injury in the acute phase, did lower the redislocation rate but recurrence is still unacceptably high (i.e., 22%)

Currently, the recommendation is non-operative treatment for the first-time traumatic LPD with no osteochondral injury requiring surgery. Larger multicenter studies with consistent inclusion criteria and defined patient variables are required to answer how to best manage the first-time traumatic LPD; which APIFs and at what threshold to treat, would help to define surgical intervention. The goal is to reduce the high recurrence, the impaired knee function and limitations in activities after patellar dislocation in childhood and reduce the risk of cartilage degeneration in adulthood.

8 STRENGTH AND LIMITATIONS

The strength of these four studies was the prospective design with a consecutive series of children 9-14 years of age. All children were skeletally immature and had a traumatic knee hemarthrosis due to a primary LPD or other knee injuries. The study cohort was from a well-defined catchment area following an algorithm in the investigation of the injury with standardized radiographs and MRI protocols. The MRI signs of an MPFL injury in the acute phase can be difficult to interpret, the MPFL injury was further investigated with arthroscopy for comparison of the findings, and for a better understanding of the injury.

The same experienced musculoskeletal pediatric radiologist reviewed the radiographs and MRI scans for all four studies. In study II the MPFL injuries were independently reviewed by an additional pediatric radiologist and the final interpretations were decided by consensus. In study III, MRI scans from 35 patients were reviewed by an orthopedic surgeon and ICC was calculated with good-to excellent results in the majority of the measurements. The participants in the control group had a similar age and geographic distribution as the LPD patients, were collected within the same time period, and underwent the same imaging protocol. The detailed description of the MPFL injury, the PF morphology and anatomic patellar instability risk factors in a defined group of skeletally immature patients with first time traumatic patellar dislocation is new information. The incidence of serious knee injuries in the general population in skeletally immature patients have not been described before. Study IV was an ISRCT registered RCT with a prior power analysis, and all patients required were enrolled and followed for two years. The randomization was carried out in blocks of six patients and stratification was done for sex, which resulted in equal amount of OT and NOT patients. They were evaluated concerning redislocation, subjective and objective knee function and anatomic imaging risk factors.

The limitations of study I, is the 8-month collection period; it would have been more precise to have at least a 12-month study period to include all variations in seasonal activities and transportation facilities. The over-representation of winter activity related injuries could be due to the study period, which did not extend to the summer months. The children in the Stockholm region often leave the area during the summer vacation time, and the hospitals are filled with deputy staff which can result in difficulties to maintain a strict set up for studies, which in turn might have influenced the quality of the registration. Thus, the study started in September and was planned to end before the summer period. This period was calculated to include at least 100 patients which was fulfilled.

A weakness of all four studies is that the upper age limit was 14 years, and therefore, we have not captured the middle age adolescents with open or closing physes. This is due to the organization of our hospital system; our ‘‘pediatric orthopedic’’ population is defined as age ≤14 years in an otherwise healthy child.

Another weakness of study II could be the exclusion of patients with large OCLs; but even in this group, the majority of the patients (81%) had an injury to the MPFL at the patellar attachment site.

The weakness of study IV is the relatively short follow-up time, although the long-term outcome has yet to been settled. The treatment considered only the MPFL injury, and the APIFs were not used in the surgical algorithm, which could have improved the outcome. On the other hand, the purpose was to evaluate if a minor surgical procedure could improve the outcome, and the high amount of APIFs in this cohort was not known before the trial started. We encouraged our patients to see PF physiotherapists, and the majority did go to recommended physiotherapists, the ability of free choice resulted in variable physiotherapy interventions. A controlled physiotherapeutic intervention program for each patient with outcomes controlled after the rehabilitation period would have been superior. Available PRO measures and functional tests for children were used, although there is still a lack of variable PRO measures, functional tests, and activity score validated for children. Even though the number of patients examined in study IV was sufficient according to the power analysis, the sample size could have been too small to show statistically significant associations between the present APIFs and patella redislocation.

9 CONCLUSION

STUDY I

Hemarthrosis after acute knee trauma in children 9-14 years of age is an important sign, as 70 % of the patients had serious knee injuries that needed specific medical treatment. Fifty-six percent of these patients had no visible injury on plain radiographs. Physicians who treat this group of patients should consider MRI to establish the diagnosis when there is no or minimal radiographic findings. Lateral patellar dislocation is the most common injury followed by ACL injuries and ATS fractures. These results should be taken into consideration to improve prevention strategies and treatment algorithms in patients with pediatric knee injuries.

STUDY II

The skeletally immature children sustain an MPFL injury in 99% after acute first-time lateral patellar dislocation. The MPFL injury is located at the patellar attachment site as an isolated injury or part of a multifocal injury. Arthroscopy and MRI complement each other in the investigation of MPFL injuries.

STUDY III

There is a significant difference in mean values of all established APIFs between our cohort of children with traumatic first-time LPD and the control group. The established thresholds for trochlear dysplasia measured as trochlear depth <3mm, sulcus angle ≥ 145° and patella alta measured as CDI ≥1,2 can be used in young adolescents. Trochlear dysplasia was the main divergent APIF for LPD in this group of skeletally immature children when described as trochlear depth and together with lateral patellar tilt (≥ 20°), they had the strongest association with LPD. The risk factors need to be taken in consideration when treating children with first-time traumatic LPD.

STUDY IV

A refixation of the MPFL injury significantly reduced the redislocation rate but did not improve the subjective or objective knee function compared with non-operative treated patients. The majority of the patients in both groups were satisfied with their knee function. No significant association was found between the anatomic patellar instability risk factors and redislocation.

10 FUTURE PERSPECTIVES

Serious knee injuries are common among children, and the majority is sports-related. Prevention strategies are important; knee control exercises should be a natural part of all sports that are knee provocative. Investigation and treatment algorithms are crucial for accurate diagnoses and treatment. Prevention strategies are important and should be fundamental for all who treat children.

The treatment of patellar dislocations needs to be individualized and based on the MPFL injury and risk factors. We have seen that the anatomic patellar instability risk factors are frequent, even in this group of skeletally immature children with first-time traumatic patellar dislocation. The anatomic patellar instability factors need to be further studied in children who experience a redislocation in order to distinguish positive differences and thresholds between patients with a one-time LPD and redislocators and address which APIFs plays the most important role to help define the risk of redislocation.

Traumatic first-time LPD with hemarthrosis results in an MPFL injury in 99% of the cases in this age group. The best non-operative method for healing without elongation needs to be further investigated.

Recent studies support that reconstruction of the MPFL is preferable to refixation/repair to treat recurrent dislocations. There are several methods to achieve safe surgery concerning open physes when reconstructing the MPFL in children. Further research is needed to determine when an MPFL reconstruction is sufficient to prevent redislocation, vs. when other surgeries might need to be added for improved outcome. These same considerations hold true for MPFL reconstruction after refixation of cartilage injuries.

Physiotherapeutic interventions and structured rehabilitation need further evaluation. Objective functional tests that are validated for children are needed to evaluate treatments and outcomes after structured rehabilitation to produce a "test battery" used for patellar instability and optimal knee function in children.

Redislocation is the main reported outcome after LPD, however there are other important outcomes; validation of PRO measures remains a continuous work effort. KOOS-Child need to be further evaluated for different knee disorders and transition into adolescent and adulthood for long term follow-up.

We have seen that osteochondral lesions are common, and recent studies have shown that recurrent patellar dislocation and non-anatomic patellar stabilization surgery seems to have a negative effect on cartilage quality. Increased knowledge of the long-term effects is crucial. MRI studies could further increase the knowledge of cartilage healing capacity after injuries to the joint surface.

Larger multicenter studies with consistent inclusion criteria and defined patient variables are needed to define the patient profile and best treatment for non-operative management, and in whom surgical treatment is recommended.

11 SWEDISH SUMMERY

Knäskador är vanliga hos barn och allvarliga knäskador är vanliga inom idrotten, men hur det ser ut i den allmänna barnpopulationen är mindre känt. En traumatisk knäskada som leder till utgjutning i leden (blödning) kan vara tecken på en allvarlig knäskada. Den vanligaste allvarliga traumatiska knäskadan hos barn är patellaluxation (knäskålen går ur led, utåt). Barn har hög recidivrisk, 30–70% riskerar att få upprepade luxationer. Upprepade patellaluxationer (instabilitet) kan leda till sämre livskvalitet med smärta, nedsatt fysisk aktivitetsnivå och på längre sikt risk för ledförslitning (artros).

Knäskålen är en viktig del i knäledens sträckapparat och bidrar till stabilitet genom att centrera lårmuskeln och förbättra den mekaniska kraftutvecklingen när man sträcker i knäled. Knäskålsleden består av knäskålen och trochlea (lårbenets ledyta som har en fåra som knäskålen glider i när man böjer och sträcker i knäleden). Stabilisering av knäskålen är komplex och är beroende av flera faktorer såsom trochleafårans djup, omgivande ledband och muskler som interagerar. Det finns anatomiska riskfaktorer för patellainstabilitet; trochlea dysplasi (grund trochleafåra), hur högt knäskålen står, eller hur vinklad knäskålen är, i förhållande till lårbenets främre ledyta samt avstånd i knäleden som påverkar lårmuskelns kraft på knäskålen.

Vid utredning av knäskador används röntgen och magnetkameraundersökning (MR). MR avbildar hela knäleden: ben, brosk, muskler, ledband, menisker och man kan diagnosticera skador, svullnad och blödning, samt riskfaktorer. Anatomiska riskfaktorer för patellainstabilitet är framtagna efter röntgen, datortomografi och MR-mätningar på vuxna. Vilka mätmetoder och referensvärden vid MR-undersökningar som är tillförlitliga även på barn är inte klarlagt.

Forskning har visat att ett ledband som förbinder knäskålen med lårbenet på insidan av knät, det mediala patellofemorala ligamentet (MPFL), är mycket viktigt för stabiliteten. Ligamentet skadas i majoriteten av fallen vid en traumatisk patellaluxation. Hur och var det skadas bedöms med hjälp av MR, men skadans svårighetsgrad kan vara svårbedömd i akutskedet p.g.a. mycket svullnad i området. Broskskador är också vanligt hos barn i samband med patellaluxation. Behandling vid förstagångs-patellaluxation utan broskskada har oftast varit icke kirurgisk; kort period med knäskålsstabiliserande skydd och efterföljande fysioterapi för att återställa styrka och stabilitet, men recidivfrekvensen är hög.

Syftet med denna avhandling var dels att beskriva nuvarande spektrum av akuta knäskador med ledutgjutning med en detaljerad beskrivning av den vanligaste skadan, traumatisk patellaluxation. Syftet var också att beskriva knäskålsledens morfologi, anatomiska riskfaktorer, hur MPFL skadas, samt att utvärdera om en akut mindre kirurgisk behandling av MPFL skadan kontra icke kirurgisk behandling av förstagångs-patellaluxation kan minska den höga recidivfrekvensen.

Avhandlingen består av fyra prospektiva studier. Samtliga studier är utförda på Astrid Lindgrens barnsjukhus i Stockholm mellan 2009–2014 och patienterna i studierna är barn 9–14 år med öppna tillväxtzoner i skelettet runt knäleden. Alla patienter har en akut traumatisk knäskada med blödning i knäleden och är i övrigt friska och utan tidigare knäskada. De undersöks enligt en algoritm med akut klinisk undersökning och röntgen samt MR inom 1-2v från skadetillfället.

Studie I
För att se dagens skadepanorama, incidens och skadeorsak, remitterades alla Storstockholmsbarn med akut knätrauma 9–14 år under en 8 månaders period till ALB och undersöktes enligt ovan. 117 patienter inkluderades och 70% hade en allvarlig knäskada (dvs.

en skada som krävde medicinsk behandling). I 56% av fallen visade röntgen normalt utfall och diagnosen ställdes med hjälp av MR. Den vanligaste allvarliga skadan var patellaluxation med en årlig incidens på 0,6/1000 i åldern 9–14 år. Den var 3 ggr vanligare än den näst vanligaste allvarliga knäskadan, den främre korsbandsskadan. Majoriteten av skadorna var idrotts relaterade och i åldersgruppen 12–14 år. Den vanligaste skadeorsaken var utförsåkning (skidåkning/snowboard). Handboll och fotboll var de kontaktidrotter som stod för majoriteten av patellaluxationerna och korsbandsskadorna.

Studie II
74 barn med traumatisk förstagångs-patellaluxation utreddes enligt ovan samt med titthålskirurgi (artroskopi) inom 14 dagar från skadetillfället för att ytterligare kartlägga MPFL-skadan. MR och artroskopi visade att 99% hade en MPFL-skada vid infästet mot patella, antingen som en isolerad skada eller som en del av en skada på flera lokalisationer av MPFL. En svullnad vid MPFLs fäste mot patella diagnosticerad vid MR-undersökning visade sig vara en skada i 99% av fallen även vid artroskopi. MR och artroskopi kompletterar varandra i utredning av skadan.

Studie III
MR-undersökningar från 103 barn med förstagångs-patellaluxation och 69 barn som kontrollgrupp utan patellaluxation från studie I jämfördes. Knäskålsledens morfologi och de olika riskfaktorerna mättes och det var en säkerställd skillnad av medelvärden för alla etablerade riskfaktorer vid jämförelse mellan grupperna. Det visar att riskfaktorerna framtagna för vuxna även är användbara på barn. Det fanns ingen åldersberoende skillnad i vår grupp. De etablerade referensvärdena för trochlea djup och knäskålens höjd är användbara i den här åldersgruppen, övriga referensvärden kan behöva en mindre korrektion.

Grund trochleafåra var den riskfaktorn som markant skilde sig mellan grupperna, 74% av patellaluxations-patienterna hade en grund trochleafåra jämfört med 4% i kontrollgruppen. Antalet riskfaktorer var generellt hög hos barn med förstagångs-patellaluxation och behöver tas i beaktan vid bedömning av dessa patienter.

Studie IV
Kan en artroskopiskt assisterad mindre kirurgi med reparation av MPFL-skadan minska risken för upprepad patellaluxation och förbättra knäfunktionen jämfört med icke kirurgisk behandling? Efter att MPFL-skadan diagnosticerats med artroskopi (studie II) randomiserades de 74 patienterna i en kliniskt kontrollerad studie till:

grupp 1) Icke operativ behandling med knäskålsstabiliserande skydd i 4v och fysioterapi,
grupp 2) Artroskopiskt assisterad reparation av MPFL, gips i 4v och fysioterapi.

Uppföljningstiden var 2 år. Antalet recidiv av patellaluxationer registrerades. Det gjordes en utvärdering med patientrapporterade frågeformulär för livskvalitet, aktivitetsnivå och subjektiv knäfunktion. Objektiv knäfunktion utvärderades med hjälp av styrketester och hopptester.

Studien visade att kirurgisk behandling med reparation av MPFL-skadan signifikant minskade recidivfrekvensen, men förbättrade inte den subjektiva eller objektiva knäfunktionen jämfört med icke kirurgisk behandling. Majoriteten i båda grupperna hade en bra knäfunktion vid två års uppföljningen.

12 ACKNOWLEDGEMENT

I would like to thank everyone who has inspired, supported and contributed to make this thesis possible. Especially, I would like to express my sincerely gratitude to:

All children who participated in the studies.

Associated Professor, **Per-Mats Janarv**, main supervisor, for your endless enthusiasm and for inspiring supervision. Thank you for all the support in research and for sharing your great clinical experience in pediatric orthopedics.

MD and PhD, **Wilhelmina Ekström**, co-supervisor and former college, for your contribution to my project with constructive thoughts, linguistic and scientific help. Thank you for your friendly support and supervision.

Professor, **Lars Weidenhielm**, co-supervisor, for your valuable support, for sharing your experience, and for giving me advice when I needed it the most.

Professor, **Elizabeth A. Arendt**, co-author. Thank you for invaluable support, for sharing your expertise in the PF-world, and for your constructive discussions. Thank you for listening and trying to understand my thoughts, for believing in me, and for our new friendship.

Radiologist and PhD, **Thröstur Finnbogason**, co-author, for your endless work with reading radiographs and MRI, and for sharing your expertise in the field.

Physiotherapist and PhD, **Christina Mikkelsen**, co-author. Thank you for professional guidance, collaboration and all work with functional testing, and for always being positive.

Physiotherapist, **Anna Hellsten,** co-author, for your extraordinary enthusiasm, and expertise in PF rehabilitation for children, for creating home training and rehab programs. Thank you for all contribution in study IV, including the children's rehab and fun collaboration.

Professor, **Zari Ponzer**, external mentor, for sharing your valuable knowledge, and for inspiring discussions.

Karolinska Institutet and the **Department of Women´s and Children´s Health**, for giving me the opportunity to become a PhD-student. Especially thanks to **None-Marie Kemp** and **Anna Sandberg** for all practical assistance.

PT, PhD, Associate Professor, **Eva Weidenhielm Broström**, Director of Pediatric neurology and musculoskeletal disorders and Home care, for encouragement and valuable support.

MD, **Stefan Gantelius**, Head of Patient Flow Pediatric Orthopedic, for giving me the opportunity to combine clinical work and research and friendly support.

MRI Department, all radiographer, for always being helpful in trying to get patients scheduled in time. Everything is possible if the will is there. Thank you! Especially thanks to Radiologist, **Ulrica Voss,** for the contribution in study II.

The staff on the Operating Ward, at Astrid Lindgren Children´s hospital in Solna, for your interest and help during the randomization period.

Statistician, **Elisabeth Berg**, for great statistical help through the years.

The staff at Teamolmed, for your professional and timely support for the children.

All friends, former and present PhD students, and researchers at Motion Analysis Laboratory, who have encouraged and supported me through the years as a doctoral student: **Marie Eriksson, Cecilia Lidbeck, Elin Löf, Josephine Naili, Åsa Bartoneck** and **Lanie Gutierrez Farewik. Kicki Löwing,** your encouragement and our discussions about research and life in general is always an inspiration to me. **Johan von Heideken,** for the first lessons in SPSS, colleague and friend far away, I miss you. **Mimmi Örtqvist,** for all creative discussions about PRO measurements and fun collaboration in collecting data. **Mikael Reimeringer,** for excellent IT-support.

Photoshop friends, **Petrus Lidbeck** and **Lukass Legzdins**, for your expertise help.

Dear Colleagues at the Pediatric Orthopedic Unit, Astrid Lindgren Children's Hospital, **Karolinska University Hospital Solna**, for all the joy of daily work. **Per Åstrand,** my room-mate, for your valuable support and good late days' discussions. Especially, I would like to thank **Eva Bengtsson Moström,** my sparring partner in the PF-field, for your support and encouragement along the way, and for your contribution as a co-author. **Georg Hirsch,** for the help in the finishing process of the thesis, and **Yvonne Haglund-Åkerlind,** my former boss, for giving me the opportunity to work with pediatric orthopedics. No one mentioned, no one forgotten at the clinic, a special thanks to the **Health professionals,** for good help and dedication in the care of our patients.

My former colleagues at the **Department of Orthopedics at Karolinska University Hospital in Solna,** for friendship. Especially, I would like to thank **Professor Henrik Bauer** and my former boss, **Professor Gunnar Nemeth,** for believing in me and giving me valuable support.

OI team, thank you for giving me the opportunity to work with you, despite my interest in knees. The team work is a pleasure.

To all my dear friends, no one mentioned no one forgotten. Thank you all for support, joy, nice dinners and our travels together. Especially, I would like to thank my friend **Anna-Karin Renström,** for your pep-talk and being a good old friend, and **Catarina Hansson,** my friend far away, but in my heart, close.

My brothers **Per** and **Sven**, with families and my families-in-law. Thank you for your curiosity, concern and encouragement. Looking forward to spend more time with you.

Håkan, my beloved husband and best friend, and our sons **Filip** and **Felix**, for your great support, and unconditional love. I could not have done this without you. My love for you is endless, you are the best!

This thesis was supported by grants from:

Her Royal Highness Crown Princess Lovisa's/Axel Tielman's Foundation, Capio Research Foundation, Sällskapet Barnavård at Karolinska University Hospital. King Oscar II and Queen Sophia Golden Wedding Anniversary Foundation, the Research Committee of the Sophiahemmet Foundation, the Skandia Research Foundation, and the Swedish National Centre for Research in Sports.

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14 APPENDICES

A Home-training and rehab program

B Flow sheet for clinical examination

C EQ-5D-Youth

D KOOS-Child

E Kujala score

F Tegner activity scale

A

SPORT & REHAB KLINIKEN

KAROLINSKA Universitetssjukhuset

Barnortopeden, Astrid Lindgrens Barnsjukhus

Hemträningsprogram efter patellarluxation, gipsbehandlad

Beroende på individuella faktorer som smärta och svullnad tar rehabiliteringen olika lång tid. Det ska således ske en successivt stegrad belastning.
Du får belasta fullt, men kryckor bör användas till dess att bra knäkontroll har uppnåtts.

Placera ditt opererade ben lite högre när du vilar

Sitt med benet högt så minskar svull-naden under gipset

Hemövningar fas 1

Alla övningar görs 2 gånger dagligen, alla övningar uförs 2x10

1. Ligg på sidan och lyft benet från underlaget

2. Lyft benet ca 5 cm från underlaget

3.Ligg på mage och lyft benet från underlaget

4.Ligg på rygg och lyft benet så mycket du kan så att det drar på baksidan av låret. Gör samma sak med andra benet

5.Försök stå med lika belastning på båda benen och gå upp på tå. Du kan ta stöd av en stol eller vägg.

6.För det opererade benet bakåt. I början kan du ha krycka eller vägg som stöd

7.För det opererade benet framåt. I början kan du ha krycka eller vägg som stöd

8.För det opererade benet åt sidan. I början kan du ha krycka eller vägg som stöd.

9.Stå på ditt opererade ben och för det andra benet framåt. I början kan du ha krycka eller vägg som stöd.

10. Stå på ditt opererade ben och för det andra benet framåt. I början kan du ha krycka eller vägg som stöd.

Ett samarbete mellan Barnortopeden, Astrid Lindgrens Barnsjukhus & Sport och Rehabkliniken
Grafisk design av Gustaf.Madenteg@hotmail.se

SPORT & REHAB KLINIKEN

KAROLINSKA
Universitetssjukhuset
Barnortopeden, Astrid Lindgrens Barnsjukhus

Rehabiliteringsprogram efter patellaluxation med refixering av MPFL-lig

Tiden för de olika stegen i rehabiliteringen är individuell, beroende på individuella faktorer som smärta och svullnad. Ibland kan man behöva stanna lite längre vid ett moment. Det är viktigt att inte hoppa över något delmoment och att successivt stegra belastningen. Övningarna behålls så länge de bedöms vara relevanta. Patient får belasta fullt men kryckor bör användas till dess att bra knäkontroll har uppnåtts. Rehabiliteringstiden ligger mellan 3-6 månader.

Fas 1 (under gipsperioden 1-4 veckor) patient tränar enligt hemprogram kontroll hos sjukgymnast.

Målsättning för perioden:

Full belastning på det opererade benet
Klara genomföra hemträningsprogram
Reducera smärta
Övningar för perioden:
Raka benlyft i fyra rörelseriktningar liggande och stående
Tåhävningar
Belastning/balansövningar
Stretcha hamstrings

Regim:
Att i vila ha benet i högläge

Fas 2 (4-6 veckor) Tid hos sjukgymnast så fort som möjligt efter avgipsning

Målsättning för perioden:

Återfå full passiv extention
Ökad flexion < 100 grader
Ingen svullnad
Gång utan hälta med kontroll i slutsträckning
God kontakt med Vastus medialis
Påbörja aktiv styrketräning av muskulatur i nedre extremitet och bål. Quadriceps tränas isometriskt och i closed chain
Klara raka benlyft

Övningar för perioden:

Trampmaskin
Roddapparat
Aktiv rörelseträning i hela rörelseomfånget med boll och liknande
Gång och stegövningar med kontrollerad slutsträckning
Isometrisk styrketräning för Quadriceps med fokus på Vastus medialis
Balansträning/belastningsövningar
Styrketräning för nedre extremitet och bål med fokus på Gluteus medius
Raka benlyft i fyra rörelseriktning i dragapparat eller med gummiband
Stående med mjuk boll bakom knäet för slutextention
Tåhävningar
Stretch för hamstrings, höftböjare och laterala strukturer

Regim:

Om patients knä fortfarande är svullet fortsätta med högläge. Stort fokus på rörlighet och slutextention

Fas 3 Sjukgymnastik 1-3 gånger i veckan. Program skrivs till skolgymnastik och hemträning

Målsättning för perioden:

God alignment och knäkontroll vid dubbla knäböj ner till 30´flexion
God knäkontroll vid gång, ej längre behov av kryckor
Ökad styrka i nedre extremitet och bålmuskulatur med fokus på Vastus medialis och Gluteus medius
Förbättrad balans och koordination
Flexion över 110 grader

Övningar för perioden:

Cykel
Closed chainövningar ner till 30´flexion med god alignment
Stretch för höftböjare och laterala strukturer
Stegrade balans och koordinationsövningar med bollar och olika balansredskap
Open chain övning för Quadriceps med rulle under knäet undvik excentrisk belastning
Styrketräning för nedre extremitet och bålmuskulatur, med fokus på Gluteus medius
QC-aktivering med muskelstimulator

Fas 4 sjukgymnastik 1-3 ggr/vecka , nytt program till skolgymnastik och hemträning

Målsättning för perioden:

Full rörlighet
God alignment och knäkontroll vid kliv upp och ner från låg step up
God alignment och knäkontroll i enbens knäböj
Sätta och resa sig från stol med belastning endast på opererade benet
Ökad styrka i nedre extremitet och bål, med fokus på Vastus medialis och Gluteus medius
Kunna utföra komplexa balans och koordinationsövningar

Övningar för perioden:

Step up övningar i olika hastigheter och riktningar
Closed chain övningar med successivt ökad knävinkel och utfallssteg med fokus på Vastus medialis och Gluteus medius
Closed chain övningar med belastning enbart på opererade benet
Open chain för Quadriceps i hela rörelsebanan med successivt stegrad belastning, fokus på slutextention men undvik större excentrisk belastning i open chain
Funktionella mer komplexa övningar för balans och koordination med boll
Riktningsförändringar
Studsmatta, små jogg och dubbelhopp
Styrketräning för nedre extremitet och bålmuskulatur

Fas 5 sjukgymnastik 1-3 ggr/vecka , nytt program till skolgymnastik + hemträning

Målsättning för perioden:

Förbättra styrka i opererade benet
Påbörja mer aktiv spänstträning
Återfå normalt löpsteg
God alignment vid spänst och snabbhetsövningar
God funktionell rörlighet

Övningar för perioden:

Fortsatt styrketräning
Djupa knäböj på ett och två ben
Djupa utfallsteg
God alignment och knäkontroll i landningsmoment på två ben från stepp
Hopprep
Jogga på jämnt underlag
Open chain övningar nu även excentrisk belastning på Q-ceps

Regim:

Patient kan i slutet av denna period börja vara med på ordinarie skolgymnastik men undvika kontaktidrotter, snabba riktningsförändringar och hopp.

Fas 6

Målsättning för perioden:

Godkända funktionella tester: sidohopp ,enbenshopp, trestegshopp, kvadraten och enbensknäböj
Uppnå minst 95% muskelstyrka i opererade benet
God knäkontroll i hopp och spänstövningar
Löpning utan smärta och med full knäkontroll
God bålstyrka
Patient vågar lita på sitt ben fullt ut
Ingen smärta eller svullnad under/efter aktivitet
Återgå till aktuella idrottsaktiviteter och att vara med fullt ut på skolgymnastiken

Övningar för perioden:

Spänst och snabbhetsövningar
Sicksack löpning, löpning med vändningar i 90, 180 och 360 grader
Fortsatt funktionellt komplexa övningar för balans och koordination med successivt stegrad belastning och svårighetsgrad
Accelerations och decelerationsövningar
Excentrisk styrketräning i open chain för Quadriceps

Sammanfattning:

Quadriceps tränas isometriskt tills dess patient har god kontakt med Vastus medialis

Vastus medialis är viktig för styrning av patella, försvagad Vastus medialis leder till lateral förskjutning av patella

Closed chain ned till 30´ med god alignment och knäkontroll, när patient klarar detta kan man börja gå djupare ner i knäböj

Hamstrings får hela tiden tränas i open chain

Open chain för Quadriceps påbörjas med fokus på slutextention och liten vinkel

Gluteus medius är viktig för att klara god alignment i knäböj, även bålstabilitet har betydelse för att kunna uppnå god knäkontroll

Avvakta med excentrisk träning för Quadriceps i open chain i minst 10 veckor

Patella är som mest instabil mellan 0-25 grader flexion och i vridmoment, därför är det extra viktigt att öva knäkontroll i dessa vinklar och moment

B

Flowsheet for follow up

Namn						
Personnummer	Samtycke					
Adress				Databas nr		
Telefonnr bostad	Randomiseringnr			A	B	
Telefonnr mobil	Skadat knä	Hö	Vä			
	Pre op		3mån		2år	
Datum						
Formulär						
KOOS-child						
EQ-5D-youth						
Kujalascore						
Tegner						
Klinisk undersökning	Hö	Vä	Hö	Vä	Hö	Vä
PF alignment- i vila tilt/ ej						
Patellamobilitet mm						
Q-vinkel °						
Genu recurvatum °						
Apprehensiontest +/-						
Låromfång 3 cm prox om patella cm						
Lachman +/-						
Sidostabilitet +/-						
Hydrops ja/nej						
Hypermobilitetstest Beighton						
VAS						
Längd						
Vikt						
Dominant ben						
Muskeltester						
Sidohopp 30cm (antal/30sek)						
Enbenshopp längd (3 försök/bästa)						
Knäböj 30 sek (enbensböj antal/30sek var/valg)						
ROM						
Isokinetisk muskelstyrkemätning						
Radiologisk utredning						
Rtg preop						
MR preop						
Rtg 2år						
Start och Uppföljning						
1:a gångslux datum						
A-scopi datum						
Antal Twinfix						
Post op komplikation/ Infektion						
Re-lux/ antal						
Hur lång tid efter a-scopi						
Sublux före?						
Hur skedde det?						
Återupptagit idrott/vilken						

C

EQ-5D-Y

Hur är din hälsa IDAG?

Sätt ett kryss i den ruta som bäst beskriver din hälsa IDAG.

Kunna röra sig

Jag har inte svårt att gå ❑

Jag har lite svårt att gå ❑

Jag har mycket svårt att gå ❑

Ta hand om mig själv

Jag har inte svårt att tvätta mig eller klä på mig själv ❑

Jag har lite svårt att tvätta mig eller klä på mig själv ❑

Jag har mycket svårt att tvätta mig eller klä på mig själv ❑

Göra vanliga aktiviteter *(till exempel gå i skolan, sport-och fritidsaktiviteter, lek, göra saker med familj eller kompisar)*

Jag har inte svårt att göra mina vanliga aktiviteter ❑

Jag har lite svårt att göra mina vanliga aktiviteter ❑

Jag har mycket svårt att göra mina vanliga aktiviteter ❑

Ha ont eller ha besvär

Jag har inte ont eller några besvär ❑

Jag har lite ont eller lite besvär ❑

Jag har mycket ont eller mycket besvär ❑

Känna sig orolig, ledsen eller olycklig

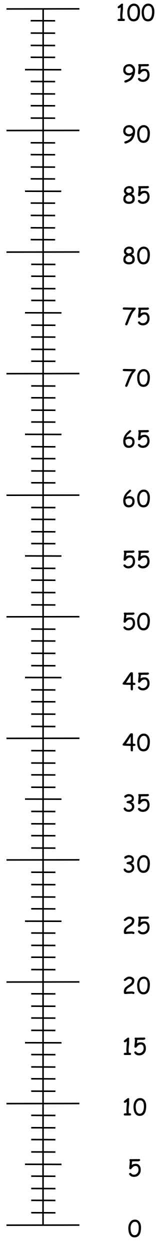
Jag är inte orolig, ledsen eller olycklig ❑

Jag är lite orolig, ledsen eller olycklig ❑

Jag är mycket orolig, ledsen eller olycklig ❑

Hur bra är din hälsa IDAG?

Den bästa hälsa du kan tänka dig



Den sämsta hälsa du kan tänka dig

- Vi vill veta hur bra eller dålig din hälsa är IDAG.
- Den här linjen går från 0 till 100.
- 100 är den <u>bästa</u> hälsa du kan tänka dig.

  0 är den <u>sämsta</u> hälsa du kan tänka dig.
- Sätt ett X på linjen som visar hur bra eller dålig din hälsa är IDAG.

D

KOOS-Child knäformulär

DATUM: ____________________ PERSONNUMMER: _____________________

NAMN: ____

INSTRUKTIONER

De här frågorna handlar om hur ditt skadade knä påverkar dig. Svara på varje fråga genom att kryssa för det alternativ du tycker är bäst (endast ett alternativ per fråga). Om du är osäker, kryssa ändå för det alternativ som känns riktigast.

KNÄPROBLEM

S1. Hur ofta har knät varit svullet de senaste 7 dagarna?

Aldrig	Sällan	Ibland	Ofta	Alltid
☐	☐	☐	☐	☐

S2. Hur ofta har du hört något ljud från knät de senaste 7 dagarna?

Aldrig	Sällan	Ibland	Ofta	Alltid
☐	☐	☐	☐	☐

S3. Hur ofta har ditt knä hakat upp sig (fastnat) de senaste 7 dagarna?

Aldrig	Sällan	Ibland	Ofta	Alltid
☐	☐	☐	☐	☐

S4. Hur ofta har du, utan hjälp, kunnat sträcka knät helt de senaste 7 dagarna?

Alltid	Ofta	Ibland	Sällan	Aldrig
☐	☐	☐	☐	☐

S5. Hur ofta har du, utan hjälp, kunnat böja knät helt de senaste 7 dagarna?

Alltid	Ofta	Ibland	Sällan	Aldrig
☐	☐	☐	☐	☐

S6. Hur svårt har du haft att röra på knät när du vaknat på morgonen de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

S7. Hur svårt har du haft att röra på knät om du varit stilla en stund senare under dagen de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

P1. Hur ofta har du haft ont i knät den senaste månaden?

Aldrig	Sällan	Ibland	Ofta	Hela tiden
☐	☐	☐	☐	☐

HUR ONT

Hur ont har du haft i knät när du har gjort följande aktiviteter de **senaste 7 dagarna**?
Kryssa för det bästa svarsalternativet för varje fråga

	Inte ont	Lite ont	Ganska ont	Mycket ont	Extremt ont
P2. Snurra/vrida på det skadade knät när du går/står/springer					
P3. Sträcka fullt på ditt skadade knä					
P4. Böja fullt på ditt skadade knä					
P6a. Gå upp för trappor					
P6b. Gå ner för trappor					
P8a. Sitta med ditt skadade knä böjt					
P9. Stå på båda benen, oberoende av hur länge					

SVÅRIGHETER VID VARDAGSAKTIVITETER

A1. Hur svårt har du haft att gå ner för trappor de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A2. Hur svårt har du haft att gå upp för trappor de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A3. Hur svårt har du haft att resa dig från en stol de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A5. Hur svårt har du haft att böja dig ned och plocka upp något från golvet de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A7. Hur svårt har du haft att gå i/ur en bil de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A10. Hur svårt har du haft att resa dig från sängen de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A12. Hur svårt har du haft att ändra läge på knät när du har legat i sängen de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A13. Hur svårt har du haft att gå i/ur badkaret/duschen de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A14. Hur svårt har du haft att sitta på en stol med ditt skadade knä böjt de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A16. Hur svårt har du haft att bära tunga väskor, ryggsäck eller liknande de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

A17. Hur svårt har du haft att bädda sängen, städa ditt rum, plocka i/ur diskmaskin eller liknande de senaste 7 dagarna?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

SVÅRIGHETER VID LEK OCH IDROTT

SP1. Hur svårt har du haft att gå ner på huk när du har lekt eller idrottat under de senaste 7 dagarna? Inte alls svårt ☐ Lite ☐ Ganska ☐ Mycket ☐ Extremt svårt ☐	
SP2. Hur svårt har du haft att springa när du har lekt eller idrottat under de senaste 7 dagarna? Inte alls svårt ☐ Lite ☐ Ganska ☐ Mycket ☐ Extremt svårt ☐	
SP3. Hur svårt har du haft att hoppa när du har lekt eller idrottat under de senaste 7 dagarna? Inte alls svårt ☐ Lite ☐ Ganska ☐ Mycket ☐ Extremt svårt ☐	
SP4. Hur svårt har du haft att snurra/vrida på det skadade knät när du har lekt eller idrottat under de senaste 7 dagarna? Inte alls svårt ☐ Lite ☐ Ganska ☐ Mycket ☐ Extremt svårt ☐	

SP5. Hur svårt har du haft att sitta på knä under de senaste 7 dagarna? Inte alls svårt ☐ Lite ☐ Ganska ☐ Mycket ☐ Extremt svårt ☐	
SPN6. Hur svårt har du haft att hålla balansen när du har gått/sprungit på ojämn mark de senaste 7 dagarna? Inte alls svårt ☐ Lite ☐ Ganska ☐ Mycket ☐ Extremt svårt ☐	
SPN7. Hur svårt har du haft att vara med på sportaktiviteter på grund av din knäskada under de senaste 7 dagarna? Inte alls svårt ☐ Lite ☐ Ganska ☐ Mycket ☐ Extremt svårt ☐	

HUR HAR DIN KNÄSKADA PÅVERKAT DITT LIV?

Q1. Hur ofta tänker du på ditt skadade knä?

Aldrig	Sällan	Ibland	Ofta	Hela tiden
☐	☐	☐	☐	☐

Q2. Hur mycket har du ändrat ditt sätt att leva på grund av ditt skadade knä?

Inte alls	Lite	Ganska	Mycket	Väldigt mycket
☐	☐	☐	☐	☐

Q3. Hur mycket kan du lita på ditt skadade knä?

Helt och hållet	Mycket	Ganska	Lite	Inte alls
☐	☐	☐	☐	☐

Q4. Hur mycket problem har du med ditt skadade knä över huvudtaget?

Inga alls	Små	Mittemellan	Stora	Mycket stora
☐	☐	☐	☐	☐

QN5. Hur svårt har du haft att ta dig till eller runt i skolan (gå i trappor, öppna dörrar, bära böcker, vara med på rasten) på grund av ditt skadade knä?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

QN6. Hur svårt har du haft att göra saker med vänner på grund av ditt skadade knä?

Inte alls svårt	Lite	Ganska	Mycket	Extremt svårt
☐	☐	☐	☐	☐

Tack för att Du tagit dig tid att besvara samtliga frågor!

E

KUJALA SCORING QUESTIONNAIRE

Name: First Last **Date:**

Physician:

1. Limp:
- a) None
- b) Slight or periodic
- c) Constant

2. Support:
- a) Full support without pain
- b) Painful
- c) Weightbearing impossible

3. Walking:
- a) Unlimited
- b) More than 2 km
- c) 1-2 km
- d) Unable

4. Stairs:
- a) No difficulty
- b) Slight pain when descending
- c) Pain both when ascending and descending
- d) Unable

5. Squatting:
- a) No difficulty
- b) Repeated squatting painful
- c) Painful each time
- d) Possible with partial weightbearing
- e) Unable

6. Running:
- a) No difficulty
- b) Pain after more than 2 km
- c) Slight pain from the start
- d) Severe pain
- e) Unable

7. Jumping:
- a) No difficulty
- b) Slight difficulty
- c) Constant pain
- d) Unable

8. Prolonged sitting with knee flexed:
- a) No difficulty
- b) Pain after exercise
- c) Constant pain
- d) Severe pain
- e) Unable

9. Pain:
- a) None
- b) Slight and occasional
- c) Interferes with sleep
- d) Occasionally severe
- e) Constant and severe

10. Swelling:
- a) None
- b) After severe exertion
- c) After daily activities
- d) Every morning
- e) Constant

11. Abnormal painful kneecap movements:
(patellar subluxations)
- a) None
- b) Occasionally in sports activities
- c) Occasionally in daily activities
- d) At least one dislocation after surgery
- e) More than two dislocations

12. Atrophy of thigh:
- a) None
- b) Slight
- c) Severe

13. Flexion deficiency:
- a) None
- b) Slight
- c) Severe

Score

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F

✱Aktivitetsnivå enligt Tegner

10	**Tävlingsidrott:**	Fotboll på nationell eller internationell nivå el div II	
9	**Tävlingsidrott:**	Fotboll på lägre nivå, div III och nedåt Ishockey, Brottning, Gymnastik	
8	**Tävlingsidrott:**	Bandy, Squash, Badminton, Utförsåkning Friidrott (hopp eller dylikt)	
7	**Tävlingsidrott:** Tennis Friidrott (löpning) Motorcross eller speedway Handboll eller basket	**Motionsidrott:** Fotboll, Squash, Orientering (motion el tävling) Bandy eller ishockey Friidrott (hopp)	
6	**Motionsidrott:**	Tennis eller badminton Handboll eller basket Utförsåkning Jogging, minst 5 ggr per vecka	
5	**Arbete:** Tungt arbete (t.ex. byggnads-skogsarbete)	**Tävlingsidrott:** Cykel Längdskidåkning	**Motionsidrott:** Jogging på ojämn mark minst 2 ggr per vecka
4	**Arbete:** Måttligt tungt arbete (t.ex. lastbilskörning, städning)	**Motionsidrott:** Cykel, Längdskidåkning Jogging på jämn mark minst 2 ggr per vecka	
3	**Arbete:** Rörligt arbete (ej tungt)	**Idrott:** Simning (tävling- el motion)	**Övrigt:** Gång i skogsterräng
2	**Arbete:** Lätt arbete	**Utomhusaktivitet:** Gång på ojämn mark	
1	**Arbete:** Stillasittande	**Utomhusaktivitet:** Obegränsad gångsträcka på jämn mark	
0	**Sjukskriven eller pensionär p.g.a. knät**		

Nu ________ **Innan Skada** ________

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Karolinska Institutet