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Medial Patellofemoral Ligament Reconstruction for the Treatment of Patellofemoral Instability in Pediatric Patients

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Statutory Declaration

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Graz, on the 19th of March 2015 Christoph Würnschimmel eh.

Acknowledgement

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Abstract

Introduction and hypothesis

Treatment of patellar instability in pediatric patients offers a challenging situation. Due to skeletal immaturity some of the therapies used for adult patients are not suitable for children. For this reason treatment of patellofemoral instability in children focuses on soft-tissue procedures. One option is the reconstruction of the medial patellofemoral ligament by using an autologous semitendinosus or gracilis tendon. This ligament plays a major role in the stabilization of the patella and its reconstruction has already showed encouraging results for the treatment of patellofemoral instability in adult patients. The hypothesis for this study was that medial patellofemoral ligament reconstruction is a suitable method for treating patellofemoral instability in skeletally immature patients and significantly improves their subjective and objective outcome.

Patients and Methods

By using subjective scores and performing a follow up examination, this study investigates the outcome of isolated reconstruction and reconstruction combined with tibial tuberosity transfer in 23 pediatric patients between the ages 14 and 18. Additionally, patella alta and trochlear dysplasia were assessed and eventual changes of patellar height after reconstruction were evaluated by comparing preoperative to postoperative radiographs,

Results

All patients had a trochlear dysplasia. Subjective scores increased significantly and general patient satisfaction in the long term follow up was satisfying. 87% of the patients would choose to re-perform this surgery if they had to decide anew. Two patients experienced recurrent subluxation and redislocation appeared in one patient. Patellar height did not decrease significantly after surgery.

Conclusion

Reconstruction of the MPFL and also combined treatment with tibial tubercle transfer in indicated knees is a valuable method for treating recurrent patellar instability effectively in adult patients as well as pediatric patients. The limiting factor is severe trochlea dysplasia which cannot be addressed with soft tissue technics.

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Abbreviations

a.p. .... anterior-posterior

CT .... Computer tomography

MRI .... Magnetic resonance imaging

MPFL .... Medial patellofemoral ligament

TTTG distance .... Tibial Tuberosity – Trochlear Groove distance

PFI .... Patellofemoral instability

Q-angle .... Quadriceps angle

STD .... Standard deviation

1 Introduction

Several studies about patellofemoral instability were published lately and new insights concerning treatment and factors leading to patellar dislocation have been gained (1) (2) (3) (4) (5) (6). Still, for responding correctly to the different entities and pathomorphologies in patellofemoral instability it is necessary to study the triggering pathomechanisms further. It is important to understand the dynamic interplay of various factors stabilizing the knee and furthermore a valid and reproducible diagnostic scheme should be established, which initiates a therapy directly addressing the underlying pathology. This study presents an overview of lately discussed pathomorphologies and treatment options. However, the focus lies on isolated reconstruction of the medial patellofemoral ligament as well as combined reconstruction with tibial tubercle transfer and its outcome in 23 patients (26 knees).

1.1 Epidemiology

The patellofemoral joint is capable of withstanding a remarkable amount of physical stress while distributing the resulting patellofemoral contact pressures equally over both lateral and medial facet of the patella (7). Nevertheless, malformations of the knee structure and overstraining lead to a big range of pathologies in this area. Besides anterior knee pain, patellar instability is a common pathology in children and young adults. While the majority of patellar dislocations are caused non-traumatically and/or as a result of minimal trauma, acute patellar dislocation represents 2 to 3% of all knee injuries and is held responsible as an important factor for traumatic hemarthrosis in the knee, osteochondral fractures, contusion of the lateral femoral condyle and soft tissue injuries. (8) (9) (10). There is an elevated rate of primary dislocation in children and young adults between the ages 10 and 19. Fithian et al (2004) described the general incidence of patellar dislocation to be 7 per 100.000 per year, while the incidence in the second decade of life increases to 31 per 100.00 per year (3). Sillanpaa et al (2008) even report of 77 dislocations per 100.000 in a young male population during their military service period, with a 100% occurrence of hemarthrosis in patients with acute traumatic patellar dislocation (11).

In a systematic review of articles by Stefancin et al (2007) subsuming 1765 patients with primary dislocation, the male-to-female ratio seems to be quite equal (46% males versus 54% females) with a tendency to females being in the majority. Females with open tibial tuberosity apophysis seem to have the highest rate of recurrent instability (12) (13). A study by Buchner et al (2005) demonstrated similar results, stating a slight shift towards female patients being at higher risk for dislocation. However, the statistical significance is too low to regard the last statement as completely true and a new study by Lewallen et al (2013) reports of a near-balanced gender distribution in pediatric patients suffering from primary patellofemoral dislocation (14).

Redislocation rates of 26% were reported after acute traumatic primary patellar dislocation, while patients under 15 years of age seem to be at higher risk (15). Because the redislocation rates seem to be dependent on the age, the initial pathology, the treatment and the follow-up time, varying information in literature is found. In another study by Maenpaa (1997) even higher redislocation rates of approximately 50% (37 patients out of 75) were reported after a median follow up 11 years after the primary dislocation, equally confirming higher redislocation rates in younger patients (16).

In the United States it is established to perform baseline therapy of primary patellar dislocation non-operatively. Still, it is important to distinguish between acute primary dislocation and habitual dislocation as the treatment options and recommendations differ widely between operative and non-operative procedures (2) (3).

1.2 Etiology and pathogenesis

The patellofemoral joint is being stabilized by a complex formation consisting of static (osseous structures), passive (capsule and ligaments) and dynamic factors like muscles and tendons. Patellofemoral instability (PFI) presents as a tendency of the patella to dislocate out of its groove. In the majority of the cases, the patella shifts laterally during movement and dislocates due to several known triggering mechanisms (17). Patellar dislocations either occur traumatically, as a result of strenuous sporting activities and/or forceful impacts or, more often, they are of non-traumatic genesis as part of structural deformation of the skeleton. Newest studies even report of a rate of 90% for non-traumatic genesis in adolescents (17) (18). This already suggests a broad range of deformities causing PFI.

Several both static and dynamic factors leading to patellar instability were described by Dejour et al (1994): Trochlear dysplasia, quadriceps dysplasia, patella alta and an excessive tibial tuberosity trochlear groove distance. More influencing factors for a primary dislocation of the patella seem to be a result of physical activity, valgus and recurvatum alignment, increased femoral antetorsion, increased external tibial rotation, and altered patellar shape and tilt (11) (19) (5) (6). James et al (1978) even proposed the term "miserable malalignment syndrome" in the context of malrotation and malalignment (20). Furthermore, Sillanpaa et al (2008) described tall height and excess weight as well as connective tissue laxity as additional risk factors for luxation (11). However, Lewallen et al (2013) could not find any associations between a high BMI and an elevated risk for recurrent dislocations (14) .

Besides direct trauma, the triggering mechanism for dislocation is described as valgus stress combined with internal rotation of the femur and external rotation of the tibia while the foot is locked in its movement (6) (11). Once the first time dislocation occurred, patients knees with above mentioned predisposing factors seem to be more likely to re-dislocate. Even non-strenuous activities and avoidance of excessive femoral internal rotation and knee valgus stress often lead to redislocation in everyday life situations; over 50% of patients continue having complaints after their first-time dislocation (11) (21).

Several studies observing their long-term consequences came to the conclusion that recurrent patellar dislocations are harmful to the patellofemoral joint causing degenerative effects, pain and osteoarthritis (2) (22) (23).

Dejour et al (1990 and 1994) introduced a categorization for patellofemoral pathologies which, simplified, divides following pathologies (19) (24):

- Objective patellar instability with existence of trochlear dysplasia and subluxations or dislocations,
- Potential risk for instability due to anatomical variations, without previous subluxation or dislocation,
- Patellofemoral pain syndrome without anatomical variations,
- Patellofemoral osteoarthritis.

Of the listed pathologies, the patellofemoral instability is the most common. Therefore it is important to understand the various causing and influencing factors that lead to it in detail, in order to be able to choose the adequate therapy.

1.2.1 Patellar development and anatomy

During Week 7 of embryonic development the patella chondrifies on the basis of a non-calcified cartilaginous complex. Between the ages 4 and 6 this complex starts to ossificate, originating from up to 6 ossification centers until they merge at the end of osseous development between the age of 13 and 16 in boys and even earlier in girls (17) (25) (26). During regular development the patella forms two joint surfaces, corresponding medially and laterally with the underlying femoral trochlea, which likewise features a medial and lateral facet separated by a slight groove. Articular cartilage covers the joint surface of the patella. A median crest separates the patella's smaller medial and larger lateral, concavely formed, articulating facets. On the contrary, the trochlear walls are convexly formed in frontal and sagittal plane and are connected by the earlier mentioned sulcus. Usually, like a matching counterpart to the larger lateral patellar facet, the lateral trochlear wall is more prominent (5). With advancing age, the thickness of the articulating cartilage decreases in both patellar and trochlear joint surface, which leads to the impression of an even deeper trochlear groove (17) (27).

1.2.2 Structural weakness and deficiency of passive restraints

Several studies pointed out the necessity of retinacular restraints in order to control patellar tracking and to prevent the patella of dislocating (28) (29).
Important passive stabilizers of the patella are the lateral and medial retinacula. Both are formed by convergent structures in their respective sides. The deep transverse retinaculum and the superficial oblique retinaculum form the lateral retinacula and arrange it into two layers. In detail, the deep layer is further divided into three more structures: the lateral patellofemoral ligament, the meniscopatellar ligament of Pauzat and the central part of the deep transverse retinaculum. The superficial oblique retinaculum stretches from the iliotibial band to the lateral part of the patella. (30) (31) (32).
On the medial part of the knee a three-layer fascial structure of the passive restraints was described by Warren and Marshall (33). The first and most superficial layer is the fascia which surrounds the sartorius muscle. Beneath this layer lies the superficial medial ligament. Corresponding fibers between the structures of layer 1 and 2 could be found;

together they form the patellar retinaculum, inserting into the patella’s medial margin. Layer 3, the deepest layer, consists of the knee joint’s capsule. Just slightly more superior lies the medial patellofemoral ligament with fibers infiltrating layer 2.

1.2.2.1 The medial patellofemoral ligament

Various origins of the MPFL were described in literature, differing mostly between the region of the adductor tubercle and the medial epicondyle; the insertion point has been specified more in detail and is agreed to a large extent (33) (34). The path of the MPFL was outlined running slightly under the VMO before adjoining to the superior two thirds of the medial patellar margin (9). Furthermore, Kang et al (2010) described the MPFL as a functional concentration of capsular fibers forming an inferior-straight and a superior-oblique fiber bundle with an angle of about 15 ± 2° in between them. Those bundles are usually not separated; for this reason the MPFL acts as one structure. Interestingly, the different bundles still act under different circumstances. While the inferior-straight bundle is responsible for static restraints, the superior-oblique bundle acts, conjoined with the VMO, as a dynamic restraint (35).

However, of all authors, Nomura et al (2005) put the most effort in analyzing the anatomical morphology of the MFPL and they concerned themselves especially with the femoral attachment. In a total of 20 knees, they measured length, width, thickness, inclination and attachment points. The MPFL seems to vary in terms of development and a range of thick, moderate and thinned out structures could be found. In their study, the mean total length of the MPFL was about 58.8 ± 4.7 mm, the width 12.0 ± 3.1 mm and the thickness in the middle part 0.44 ± 0.19 mm. In the most cases, patellar attachment of the MPFL was found being around 27 ± 10 % apart from the superior edge (measured from the longitudinal patellar height). Finally, they located the femoral attachment superior and posterior to the medial femoral epicondyle and slightly distal to the adductor tubercle. In numbers, they found the anterior edge attachment being 9.5 ± 1.5 mm proximally and 5 ± 1.7 mm posteriorly from the medial femoral epicondyle’s center and lying 61% ± 4% apart from the anterior edge of the medial femoral condyle’s antero-posterior length (36).

The main function of this ligament consists of restraining abnormal lateral drifts of the patella during movement. In complete acute patellar dislocation, the MPFL gets injured or ruptures in about 87% of the cases, according to an MRI – study by Elias et al in 2002 (2)

(9). It is important to know that the MPFL is a structure which is capable of enduring physical stress up to 208 Newton despite its thin appearance (37) (38). Thus, the MPFL takes the main part of preventing patellar dislocations, while other passive medial structures such as the patellomeniscal and tibiopatellar ligament only contribute a small amount to patellar stability. Still, the former ligaments seem to inherit functions of neuromuscular feedback, providing proprioceptive information during patellar movement in order to control proper positioning (39).

Several studies and biomechanical evaluations of cadaveric knees were performed in order to be able to estimate the crucial necessity of the MPFL. According to studies by Elias et al and Desio et al (2002, 1998) the MPFL contributes 50-60% of the total restraining force against lateral patellar displacement. 13% of the restraining force derives from the medial patellomeniscal ligament and, interestingly, the lateral retinaculum contributes 10%. Given this information, Desio clearly points out the additional damage a surgeon could cause when performing a lateral release in patients with patellar instability (9) (34). Different authors came to the conclusion, that the MPFL and its accompanying medial structures mostly stabilize the patella in the range of movement between 0° and 30° and even up to 60° in a cadaveric biomechanical study by Zaffagnini et al (17) (39) (40) (41) (42). Around 30° of flexion a critical point of particular susceptibility for patellar dislocation is reached. After that, the patella's tendency to dislocate decreases with increasing flexion, mostly because of growing stability due to trochlear glide. In the majority of the cases patellar shifts tend to dislocate laterally. In more than 90% of cases of primary lateral dislocation the MPFL gets torn or injured (34) (40).

In their kinematic study, Zaffagnini et al (2013) found an important difference of restraining function in loaded and unloaded conditions. Apparently, patellar shift and tilt of both MPFL resected and MPFL intact knees showed similar behavior in unloaded conditions. They emphasize the important role of the MPFL during high stress motion but also point out the lack of medial restraint during neutral knee flexion. Applied lateral forces in MPFL-deficient knees between 30° and 60° flexion lead to drastic patellar shift, causing dislocation. Additionally they point out the drastic change of patellar motion of knees in MPFL intact and resected condition while flexion (42).

This information suggests that muscle alignment is considered a minor preventive factor for patellar dislocation, as the active muscular stability widely depends on passive structural stability and is not set up for compensating passive or static deficiencies (3).

1.2.3 Trochlear dysplasia

During flexion and extension, the patella glides through several stages of the patellofemoral joint. In healthy knees, every degree of movement is supported by respective structures interacting with the patella. In full extension, the patella lies on the superior lateral aspect of the femoral sulcus. As mentioned in 1.2.2.1, the MPFL is responsible for stabilizing the first 30 degrees of flexion. In further flexion, from approximately 30° to 100° the patella glides into the trochlear groove giving it increasing stability, as the lateral osseous walls build up while the groove continuously deepens (43) (44). Finally, the patella gets supported tightly by the osseous structures and gains additional stability by gliding into the femoral notch at 90 degrees of flexion (17) (45). If the trochlea is dysplastic, the trochlear groove is too shallow or even convex (with an excessive sulcus angle of over 145-150°, while the normal mean value is 138 ± 6) and the relative height of the lateral condyle and the lateral trochlear slope are decreased (46) (47) (48). Thus, the physiological tracking function and the lateral anatomic barrier for the patella are lost. Hing et al (2006) studied the trochlear groove morphology in patients with PFI. They accord with the stated considerations and could point out another important factor: if the trochlear groove lies - regardless from groove shape – more medially, the tendency of the patella to dislocate is higher (49). This implicates, that the trochlear groove shape seems to be less important than position of the groove. Caton (1989) additionally showed that a patella alta (see also 1.2.5) can be provoked, as the patella cannot track along the trochlear groove but gets pushed proximally and laterally due to the lack of a lateral barrier (50). A concomitant trochlear dysplasia was found in 96% of patients with PFI and is regarded as an important, if not main risk factor for patellar dislocation (19).
The first definition for trochlear dysplasia has been proposed by Walch and Dejour H. in 1989, sub-dividing dysplasia in 3 stages of severity by assessing lateral radiographs of the knee (51). Later, Dejour D. et al corrected the old “3-stages” model and replaced it with the nowadays commonly known “4-stages” model (43) (52). In all cases of trochlear dysplasia the trochlea is shallow and in a pathologic medial position while the slope ascending to the lateral condyle is decreased (47) (53). On strictly lateral radiographs of the knee with superimposition of the posterior condyles, Dejour D. described following observations:

In the lesser severe stages of trochlear dysplasia both femoral condyles appear symmetrical and the radiographically visible line which defines the intercondylar groove crosses the condyles' facets in the trochlea's anterior upper part. This "crossing sign" implicates a flattening trochlear groove and thus trochlear dysplasia, as the point of crossing represents the location where the deepest point of the trochlear groove reaches equal height with the medial and lateral condyle. An appearance of the crossing sign further distally is susceptible of a higher grade of trochlear dysplasia. According to Dejour, this sign is found in 96% of patients with PFI and in only 3% of persons without symptoms of PFI. Another finding indicating the severity of trochlear dysplasia is the "double contour sign". This sign appears if the medial condyle is hypoplastic and appears posteriorly to the lateral condyle, producing a radiographically parallel line to the line formed by the anterior aspect of the lateral condyle. Likewise, the "supratrochlear spur", a bump or prominence of the proximal trochlea, was found in patients with trochlear dysplasia and usually appears in more severe stages.
With this information, taking into account the crossing sign, supratrochlear spur and the double contour sign, it is possible to grade trochlear dysplasia according to D. Dejour's newer classification A-D, using strictly lateral radiographs and axial CT scans in 30° flexion (48):

Dysplasia Type A: Appearance of the crossing sign, while the trochlear morphology is just slightly impaired and flattened. However, the sulcus angle exceeds 145°.

Dysplasia Type B: Appearance of the crossing sign, supratrochlear spur and a flat or convex trochlea.

Dysplasia Type C: Appearance of the crossing sign and the double-contour sign. (Convexity of the lateral facet and hypoplasia of the medial facet)

Dysplasia Type D: Appearance of the crossing sign, the double-contour sign and a supratrochlear spur. The medial and lateral trochlear facets are asymmetrical and increasingly show a "cliff pattern" due to the difference in heights.

Still, diagnosis of trochlear dysplasia may be challenging if patients do not show symptoms of patellar instability and even present with a normal knee function. Therefore, the only possibility to reveal lesser pathologies in the knee is investigation by transverse MR imaging, as sequential cuts may offer more specific information of the trochlea's upper part, which is more susceptible of dysplastic malformation (9). An MRI study by Nelitz et al in 2014 contributed some more knowledge for differentiating between the different dysplasia types and investigated the distribution of Dejour's types along 80 patients, presenting the following result (54):

- 25 were categorized into being type A,
- 23 into type B,
- 18 into type C
- And 14 into type D.

However, they pointed out, that some newly discussed MRI criteria for the diagnosis of trochlear dysplasia in order to evaluate the risk for recurrent patellar dislocation could not be correlated with Dejour's classification of trochlear dysplasia. For instance, the lateral trochlear inclination (LTI), investigated by Carrillon et al (2000), showed utilizable results only in severe trochlear dysplasia. The LTI is a line drawn tangentially to both femoral condyle's posterior subchondral bone surfaces crossed with another tangentially drawn line to the lateral trochlear's facet subchondral bone (54) (55). Still, according to Nelitz, the LTI and other measurements of the femoral trochlea such as the trochlear facet asymmetry and trochlear groove depth can be used for differentiating the low-grade (A) from the high-grade dysplasia (B, C or D).

1.2.4 Quadriceps dysplasia

The MPFL and fibers of the VMO are interacting closely. Mutually, they enhance their stabilizing function in the patellofemoral joint, controlling the moving trajectories of the patella. Kang et al (2010) investigated the crucial role of the "MPFL – VMO - interaction" during knee flexion. As the VMO starts to contract in flexion, the superior-oblique bundle of the MPFL is pulled proximally by the fibers of the VMO connecting with it. Thus, the superior-oblique bundle appears shortened during flexion. As a result they associated that the superior-oblique bundle in co-function with the VMO provides the major dynamic medial patellar stabilization. On the other hand, without VMO contraction, the superior-oblique bundle commits its stabilizing function to the inferior straight bundle by relaxing its fibers while the inferior straight bundle gains tension. Thus, according to Kang, this lower fiber bundle acts as a static medial stabilizer restraining the lateral force that works on the patella caused by the Q-angle (Q-angle see 1.2.7) (35).
However, there is still no valid consensus about the importance of the VMO concerning the patellofemoral movement and tracking during flexion. In 1998, in a cadaveric study with six knees, Fahramand et al observed the patella's behavior and concluded that in between 15° and 75° degrees of flexion applied muscle forces did not influence translation (56). Restrictions to this study have to be made though: firstly, the experimental conditions and the "in vitro" setting of applied muscle tension differ widely from what could occur "in vivo" and secondly, the specimen knees did not suffer from other pathologies or structural deficits. Therefore, a regular trochlear morphology catches the patella's glide quite early and no corrective muscle forces have to be applied.
Despite the controversial data, the VMO is considered a dynamic stabilizing factor of the patellofemoral joint. Nonetheless, there is lesser protection against dislocation in extended knees or minor flexion. Significant stabilizing effects do not occur before knee flexion reaches about 60°; at this point, fibers of the VMO start acting perpendicularly to the direction of possible lateral patellar dislocation (17) (57). Additionally, starting from 90° flexion, the patella glides into the femoral notch making dislocation even more unlikely as the patella gets guided and controlled by the quadriceps muscle with fibers of the vastus medialis muscle running contrarily to direction of dislocation (17) (57) ; of course, the restraining function of the VMO in flexion around 90° has to be regarded negligible, as the static osseous guiding factors take the lead. In 1994, Dejour H. stated quadriceps dysplasia

as an important factor for developing PFI, observing an occurrence of 83% in symptomatic patients (19). In these patients, the insertion of the VMO in the upper aspect of the medial patellar edge, respectively in the previously mentioned bundles, is incomplete or missing completely. Thus, by joining the quadriceps tendon instead of the patella, the VMO cannot develop its restraining potential or is at least severely limited in its function (32) (58). In a study by Nove-Josserand and Dejour D. in 1995 they experienced increased patellar tilt (Patellar tilt see 1.2.6) as a result of patellar instability in patients with vastus medialis dysplasia, showing values of 28.8° ± 10.5° versus 11.8° ± 5.7° in the control group (59). According to them, patellar tilt in extension is the clinical manifestation of quadriceps dysplasia and should be regarded pathologic over 20°. However, they do not restrict themselves to VMO dysplasia but regard a whole functional disorder of the quadriceps muscle as reason for patellar tilt. Likewise, dysplasia or hypoplasia of the vastus medialis is often present in many patients who do not suffer from patellofemoral symptoms. Still they may be more susceptible of degenerative changes in the patellofemoral joint (59).
Concluding, it is still important to consider that muscles are not essentially designed for compensating passive structure deformities - even if fibers act contrarily to direction of dislocation, they still have to be activated in order to act against lateral movements of the patella - and therefore, if patients present with patellar instability, efficient diagnostics among the already mentioned “static”, “dynamic/active” and “passive” factors should be performed.

1.2.5 Patella alta

Patella alta (high-riding patella) is a condition where the patella lies exceedingly superior above the trochlea and is associated with PFI as the patella cannot interact sufficiently with the trochlear groove. Therefore it just gets in touch with the most proximal parts of the trochlear groove which are not deep enough for sufficient osseous patellar guidance (60) (61) (62). The grade of influence for inducing PFI is still not known exactly as it is difficult to estimate the laterally acting forces acting on the patella when the quadriceps contracts actively. As a result, “in vitro” findings trying to correlate patella alta with patellofemoral malalignment while the quadriceps is relaxed are blurred and have to be considered with care (7). A new study by Ward et al (2007) tried to take in the factor of quadriceps activation and measured patellar height compared with trochlear alignment and contact area surfaces in patients with diagnosed patella alta while the quadriceps was contracted (61). They concluded that patellar height plays an important role in patellofemoral malalignment: patients with patella alta had a 20% higher rate of lateral displacement and 39% presented with increased patellar tilt. Additionally patella alta leads to reduced contact-surface areas between patella and trochlea. Furthermore, by presenting this data, they support the hypothesis of elevated joint stress levels in patients with patella alta. All this information is consistent with the findings of Dejour H. et al (1994), who found patella alta in 24% of patients with PFI and reinforces the studies by Insall et al (1972) who correlated recurrent dislocation with a high-riding patella (19) (62).

1.2.5.1 Patella alta in adult patients

Insall and Salvati (1971) were the first authors who successfully concretized and established an accepted definition for patella alta in adults (60). Their "Insall-Salvati ratio/index" had to comply with following requirements: it had to be performed easily and repeatedly without causing too much intraobserver-variability and thus being reliable and accurate. Furthermore, it had to be possible to measure the ratio in different flexed knee positions and be independent of joint size and magnification of the radiograph. Because the Insall-Salvati ratio meets those requirements, it was accepted widely for diagnosing patella alta. Subsuming, the Insall-Salvati ratio divides the patellar tendon length by the length of the patella itself. It is possible to measure those lengths by caliper or lateral radiographs, however using former should be used for diagnosis while caliper measurements are more appropriate for screening of patella alta (61). The patella tendon length is measured from the inferior pole of the patella to the insertion of the tendon in the tibial tuberosity. The patellar length means the greatest vertical length from pole to pole. The original ratio separating a patella alta from a patella baja was set by Insall and Salvati to be < 0.8 for patella baja and > 1.2 for patella alta. However, modifications have been made by Shabshin et al in an MRI study who expanded the strictly set ratio, additionally stating a difference of ratios in males and females (63). Accordingly, the more forgiving definitions for patella alta and baja are 1.52 and 0.79 in females and 1.32 and 0.74 in males. Still, there is no clear consent and some authors prefer to use the original index (61).

In 1992, Grelsamer and Meadows modified the Insall-Salvati ratio. They pointed out the weakness of the original Insall-Salvati ratio, whereupon it is quite insensitive in patients with unusual patellar shapes. Thus, patients who had a long non-articulating facet distally of the articulating facet tended to have the most inaccurate values for patellar height (64). Instead of measuring the length of the patella tendon itself, this ratio uses the distance between the tibial tendon insertion and the lower end of the patella's articulating surface. Former, divided by the overall length of the patella's articulating surface results in the "modified Insall-Salvati ratio", which declares values above 2 as patella alta. With this updated version of the traditional ratio, according to Grelsamer and Meadows, one half of patients who initially were not diagnosed with patella alta were detected.

Another pioneer in diagnosing patella alta and baja is Caton J. In 1982, together with Deschamps G. he proposed the "Caton-Deschamps ratio" for assessing vertical height of the patella (65). In sagittal views with the knee flexed between 10° and 80°, this method calculates the ratio between, of the one part, distances between the anterosuperior border of the tibia and the inferior end of the patella's articulating surface and, of the other part, the length of the patella's articulating surface. This index declares values above 1.3 as a patella alta and beneath 0.6 as low riding patella (patella baja) (50) (66). Dejour H. used the Caton-Deschamps index for diagnosing patella alta in his anatomic radiographic study and found a high riding patella in 24% of the patients suffering from PFI (19).

Blackburne and Peel proposed a method which is completely independent of the tibial tubercle and the patellar tendon (67). This makes a big difference in diagnosis as they state several diseases which could influence the measurement of the tendon length, causing incorrect results. On the one hand, the insertion in the tibial tubercle may be altered, like it is in Osgood-Schlatter's disease or the tubercle is simply non-existent or only shows shallow prominence. On the other hand, the tendon's origin may be affected and blurs the exact spot for measurement in the area around the patella's lower pole like in Larsen-Johansson's disease. Blackburne and Peel tried to avoid those issues by introducing their method, performed on lateral radiographs of the knee in at least 30° flexion; they require this degree of flexion as they explain the necessity of a tensioned patella tendon. A horizontal line along the tibial plateau is drawn: the distance between this line and the inferior end of the patella's articulating surface makes the dividend, while the length of the patella's articulating surface makes the divisor. This ratio provides the patellar level and physiological ratio was defined as 0.8. Values higher than 1.0 suggest patella alta, lower than 0.54 indicate patella baja (6) (66) (67).

Another attempt to evaluate patellar height was made by Labelle and Laurin (68). This method requires a lateral radiograph of the knee flexed to exactly 90°. This restriction makes the method difficult to perform in all patients and as a result it's usually not the method of choice. Theoretically, this method is similar to the clinical investigation of the knee in which a patella alta is diagnosed if the patella points upwards in 90° flexion instead of pointing forward (69) (111): a line is drawn along the anterior femoral cortical line and, if the patella's upper edge lies superiorly to it, a patella alta can be diagnosed. Several other drawbacks of this method are obvious: firstly, due to the nature of the investigation, it is not possible to diagnose patella baja. Secondly, it is difficult to draw a correctly straight line tangentially to the femoral cortex, as the femur is usually not completely straight (68) (69) (70).

Apparently, plenty of methods for measuring patellar height in adults exist. In the clinical setting, it is important not to rely on one method only but to evaluate every knee distinctly and choose individually. In 2000, Seil et al tried to compare the previously stated methods in order to recommend a certain method in terms of reliability and interobserver variability (70). However, it was not possible to clearly recommend a method as quite impressive differences in diagnosing patella alta have occurred, depending on which method was used. In conclusion, they observed the Insall-Salvati ratio and the proposal by Labelle and Laurin as the methods which found the highest number of pathologic patellar heights, while the Caton-Deschamps-index judges questionably deformed knees rather as being healthy. Overall, the Blackburne-Peel ratio showed the most moderate distribution and a low interobserver variability which lead Seil to recommend this method, by trend, over the others (70). This goes hand in hand with a review by Phillips et al (2010), who stated that the established methods only have been accepted as the "gold standard in dispute" as no alternative methods have been brought up for years (69). According with Seil, they observed that none of the methods are appropriate a hundred percent. However, they come to the conclusion that the methods by Blackburne-Peel and Caton-Deschamps are the most reliable.

Lately, a new method has been proposed by Nizić et al (2014), who tried to establish a new reference line which indicates patella alta. On lateral radiographs, it is possible to draw a line through the long axis of the femoral condyles and simply move this line parallel through the crossing of the posterior contour of the femur shaft with the condyles. If the patella crosses this line, the patella is considered high-riding. They emphasize the benefits of their option being fast and uncomplicated. Furthermore, no calculations have to be made

and it is independent of tibial structures, as only the femur and the patella are part of this construction (66).
The results are encouraging and hopefully give new directions in diagnosing patella alta. However, some authors suggest that the future of research for patellar height assessment will most likely be the use of MRI (66) (69). The „patellotrochlear index“, described by Biedert and Albrecht (2006), seems to be the first efficient step towards introducing MRI to diagnosing patella alta. By using this method, it is possible to gain a deeper insight into the individual physiological articular biochemechanics, as the investigator can concentrate on chondral features rather than bony ones (71). Hence, their index focusses on the ratio and patellofemoral constellations between the patella's articular cartilage and the trochlear cartilage. Therefore, they describe the baselines of both being as follows: the patellar cartilage baseline stretches from the most superior to the most inferior points of cartilage surface on the patella, while, in order to compare the articular interference, the trochlear baseline stretches (moved in parallel to the patellar baseline) from the most superior point of trochlear cartilage to the level of the most inferior point of patellar cartilage. The inferior end point for the trochlear baseline results from a right angle to the patellar baseline, drawn through the most inferior point of patellar cartilage. According to their inventors, the patellotrochlear index defines values above 50% as patella baja and values beneath 12.5% as patella alta (71). This method seems to be quite efficient, especially because the patient's individual patellofemoral condition can be investigated thoroughly.

1.2.5.2 Patella alta in pediatric patients

Trying to establish concrete definitions or routines for detecting patella alta is hard enough. However, the lack of ossification in pediatric patients even worsens the situation. Clearly, it is not possible to compare adult knees with knees still showing open growth plates and therefore, the established methods for investigating patellar height in adults cannot be applied in equal measure in children and adolescents (69) (72) (73). In 1986, Micheli et al described and evaluated patellar heights in children. They analyzed 19 children's knees and their patellofemoral behavior during growth spurts by using orthoroentgenograms in intervals of six to twelve months in up to 10 years of investigation (69) (72). The results are interesting as they linked proximal patellar movement with femoral growth rate and correlated overgrowth during the growth spurt with occurrence of patella alta; this applies especially in girl's patellae (72). However, Phillips et al (2010) made some restrictions to those findings. They criticize that Micheli's measuring method did not integrate the patient's ages and, as a matter of fact, neglects the fact of skeletal maturity. The radiographs were performed a.p. and the length of the patellar tendon was calculated by taking the distance between the patella's inferior edge and the tibial plateau. Accordingly, Phillips stated that it was not possible to evaluate the full ossification and therefore the high number of diagnosed patellae altae may have to be revised (69). Nevertheless, another study by Walker, Harris and Leicester in 1998 could also point out the accumulation of high Insall-Salvati ratios in young children: they observed that the ratio decreases and conforms to adult values at the age of 10 in girls and 12 in boys, while full ossification occurred later, between 15 years of age in girls and 17 years of age in boys (69) (74).

Apparently, there is a need of methods that apply to children and their special situation, lacking full ossification and therefore not being eligible for adult measuring methods. Koshino and Sugimoto described a new technique in 1989, which tried to fit those needs (73). With this method it is possible to exclude the influencing factor of ossification and therefore no adjusting is needed. By using the patella and the epiphyseal midpoints of both distal femur and proximal tibia, they measured two distances: the first was the patellotibial distance, between the patella's center and the tibial midpoint, and the second was the tibiofemoral distance, between the respective midpoints. This ratio - patellotibial distance divided by tibiofemoral distance - was calculated with lateral radiographs of 59 knees of 36 healthy children, all in between ages 3 and 18 (with an average of 10.6 years) and knees flexed between 30° and 90°. The results are remarkable, as they diagnosed patella alta in only 3.4 % while an "adult"-ratio, like the Insall-Salvati, found 67% of the knees being with patella alta (69) (73). This impressive study once more points out the incongruity of adult and growing knees in diagnosing high riding patellae.

However, not all of the previously described ratios for adults may be unsuitable for children and adolescents. Luckily, some of them can also be used quite effectively for growing knees. Aparicio et al (1999) performed an investigation of 36 lateral radiographs of children's knees, with three observers measuring patellar height with three different methods (75). Thereby, they tried to find a method which shows the best interobserver agreement in diagnosing patella alta. Of the tested methods – Caton-Deschamps, Blackburne-Peel and Koshino – they found the Caton-Deschamps ratio being the most promising. However, all three generally had a low interobserver variability and therefore may be suitable for measuring patellar heights in children. All the same, Aparicio could not confirm reproducibility being nearly as high for the other methods and thus suggests the Caton-Deschamps method, as it is a simple and reliable method and seems to be equally independent of skeletal maturity (66) (69) (75).

1.2.6 Patellar tilt and patellar shape

1.2.6.1 Patellar tilt

Similar to a high riding patella, lateral patellar tilting may cause alterations in patellar movement during flexion (6) (19). However, there is no final consent in terms of defining a physiological patellar tracking route; in fact the patella does not follow a strictly linear route along the trochlear groove but, even in healthy people, rather gets exposed to a variation of several translational and rotational forces, tilting medially and laterally while moving in posterior, distal and lateral directions (43) (76). Patellar tilt is a condition indicating the patella's internal-external rotation and is defined as angle between the femoral condyles and the patella. In order to calculate this angle in axial illustrations, a line is drawn along the condyles and compared with another line drawn through the patella's axial main axis (77) (78) (79). Another option for assessing patellar tilt was used by Elias et al (2002) in their MRI - study of acute lateral patellar dislocation. On transverse images, they obtained the angle by drawing one line through the lateral patellar facet and joined it with another line drawn through the most anterior aspects of the medial and lateral femoral condyles (9) (80). Two simple differentiations in diagnosing patellar tilt with those methods have to be made: according to Elias, a physiological angle is described as an angle opening laterally, while a pathologic angle and therefore exceeding patellar tilt is found if the angle opens medially or the drawn lines appear at least parallel. With those definitions, Elias found pathologic patellar tilt in 43% of patients with acute lateral patellar dislocation (9). However, patellar tilt is not necessarily a consequence of dislocation but rather is a risk factor provoking it (19) (59).
As further above mentioned, vastus medialis dysplasia is a factor closely related to occurrence of patellar tilt. Nove-Josserand and Dejour D. (1995) described a clear increase in values of patellar tilt angles if this muscle is dysplastic (Quadriceps dysplasia see 1.2.4) (59). Furthermore, they set a threshold for diagnosing excessive patellar tilt in extension at

20°, trying to include the variations caused by contraction and relaxation of the quadriceps. If the muscle is relaxed, the tilt is based more on the morphology of the underlying trochlea, while patellar tilt changes with quadricipital contraction and increases in patients with PFI (5) (59). Thus, patellar tilt can be provoked by several factors and an obvious etiology can often not be found. Besides quadriceps dysplasia, another important factor provoking increased patellar tilt is the trochlear dysplasia. As mentioned earlier, trochlear dysplasia leads to patellar maltracking as the patella cannot glide safely along the groove, and even gets pushed laterally and proximally, affecting patellar tilt (81) (82). However, it is important to consider the individual interactions and to try to analyze if patellar tilt causes patellofemoral instability or, alternatively, if patellar tilt is just an associated expression of other pathologic transformations in the knee.

1.2.6.2 Patellar shape

Another influencing factor in PFI might be the patellar shape. However, there is still no clear information, and some studies correlating those entities give different opinions and statements (5) (16) (83) (84). Already in 1941 a classification for patellar shapes on the basis of the medial and lateral facet has been made by Wiberg G (85). By comparing the individual composition of the medial and lateral facet and their morphological interaction, three general types (A-C, I-III) have been distinguished (excluding hybrid forms and subtypes):

Wiberg Type A/I: in this type both facets are concave and the median crest splits both facets rather equal in size. This type appears in about 10% - 16% in the normal population. According to a study by Panni et al (2011), 15.7% of patients patellas with objective PFI have been categorized into being Type A/I (5) (43) (86).

Wiberg Type B/II: the second type shows a still concave, but flattening and size-decreased medial facet with sometimes even slightly convex forms in few cases. Apparently, this shape is the most common in the normal population with a prevalence between 65% and 80%. Of the patients with PFI in Panni's study (2011), 60.7% showed this type (5) (43) (86).

Wiberg Type C/III: the medial facet is now completely convex and considerably smaller than the lateral facet. The prevalence of this type lies in between 12.9% and 25% in the normal population and is 23.6% in cases of PFI according to Panni. The male population tends to have higher rates of dysplastic Type C patellae (5) (43) (86).

Lately, patellar shape was re-introduced in the discussion as factor in PFI (5). In 1976, Cross and Waldrop could demonstrate a significant correlation between patellar subluxation and patellar morphology: considering 1004 radiographs, they described the medial facet of the patella being smaller as the lateral facet, with the median crest correspondingly being situated rather medially. Because this crest articulates with the trochlear groove, the overall position of the patella is situated more laterally and thus predisposes for subluxation (83). However, Larsen and Lauridsen (1982) could not confirm this correlation and as a matter of fact no clear data could be demonstrated (84). Later, in 1997, Maenpaa and Huhtala could once again confirm that the incidence of recurrent patellar dislocation is doubled in patients with unstable and dysplastic patellar types (16). Additionally, Panni et al (2011) presented some new discoveries. For a start, they found patellar shape closely connected with patellar tilt. Moreover, they could find a correlation between Wiberg C types and severe trochlear dysplasia, while other patellar shapes showed no connection with trochlear dysplasia (5). Nevertheless, those findings will be a matter of discussion as it is not clear how those findings could be used in clinical practice.

1.2.7 Q-angle and TTTG distance

1.2.7.1 Q-angle

The first study which tried to implement a biomechanical measure of occurring force vectors in the knee causing patellofemoral pain and PFI was performed by Brattstroem in 1964 (87). By defining the Quadriceps angle (Q-angle) it was possible to assess the associated forces of both quadriceps femoris muscle and the patellar tendon and thereby get an insight in patellofemoral dysfunction (87) (88) (89). The angle is measured between a line drawn in between the anterior superior iliac spine and the center of the patella and another line stretching from the tibial tubercle to the very same patellar center (88) (90) (91). High Q-angles over 15-20° imply large force vectors and increased peak pressures in lateral direction: besides being connected to patellofemoral pain, biomechanical considerations presume patellar subluxation tendencies (7) (88) (89). Although the geometrical construction is performed equally in other studies, no standardized procedure exists and different initial positions for assessment have been described in literature. One method trusts in measuring patients goniometrically lying in supine position with a fully extended knee and a relaxed quadriceps muscle (92); other authors measured the Q-angle in standing patients with contracted quadriceps muscle, producing deviant values (93) (94). As there exists no standardized method, values cannot simply be compared and thus makes it hard to evaluate the Q-angle in clinical practice, causing disagreement on its validity (88) (89) (94). For this reason, some authors decided to switch their protocol and introduce CT-imaging in measuring the Q-angle (95); Tsujimoto et al (2000) took it even further and suggested a modified Q-angle, to be calculated by the means of CT-imaging, with the most concave point of the intercondylar notch as a new reference point, replacing the center of the patella (90). Additional controversies exist in the weighting of pathologic Q-angles. In a review by Livingston (1998) two major restrictions have been brought up: firstly, there seems to be quite a big overlapping of asymptomatic patients and symptomatic patients, with Q-angles ranging widely. Secondly, much bigger angles have been reported in young adult women in comparison to males (89) (94). In fact there is also still no clear evidence if there is a correlation between Q-angle and PFI (88) (96) . It is conspicuous, that patients with subluxation of the patella apparently tend to have decreased Q-angles, presumably because those patellae are usually positioned more laterally (88) (91). France and Nester (2001) could demonstrate that lateral displacement of 1 mm decreases the angle by 1.1° (97). Hence, the physiological range of the Q-angle and its changes caused by different factors should be studied further. Also the different values for men and women should be reconsidered and a standardized protocol for measuring the Q-angle needs to be set, in order to establish it as a standard in clinical practice (88) (89). However, a disagreement in the validity of the Q-angle will persist in the future; Freedman et al (2014) even spoke themselves out against the use of it as they could not find the line of action of the quadriceps in correlation with the Q-angle and therefore declared it inappropriate to assess patellofemoral kinematics with it (98).

1.2.7.2 TTTG distance

Goutallier et al (1978) were the first authors who described another method of validating patellofemoral dysfunction and established a quantifiable method which does not show such high rates of interobserver variability like the Q-angle (99) (100). In axial scans the tibial tuberosity-trochlear groove distance (TTTG - distance) is the distance between the deepest point of the trochlear groove and the most anterior point of the tibial tuberosity. This distance is taken on a line which runs tangentially to the posterior condyles; therefore both points need to be referred on this tangent by constructing a perpendicular line to it (101). Initially, the TTTG was measured using axial radiographs of the knee flexed in 30° (99). In order to produce more reliable results, Dejour H. et al (1990) described a more sophisticated version of measuring the TTTG-distance. By using the means of CT two slices are getting superimposed, one at the level of the tibial tuberosity and the other at the deepest point of the trochlear groove (19) (24). However, CT lacks in qualitatively assessing others than bony structures and high doses of radiation have to be considered (102). A corresponding reaction to this was the introduction of MRI in assessing TTTG distance, which shows to be a modern and reliable method with more advantages in terms of eventual pre-operative planning (100) (102). Despite the obviously better interobserver-reliability compared to the Q-angle, still a high variation in normal values for TTTG-distance exists. Dejour H. et al (1994) found distances of 12.7 ± 3.4 mm for the normal population, Wittstein et al (2006) 9.4 ± 0.6 mm, Alemparte et al (2007) 13.6 ± 8.8 mm and Pandit et al (2014) found 10 ± 1 mm ; in 1994, the upper physiological limit was set at 20 mm by Dejour H. et al (19) (102) (103) (104). Those variations might be explained due to different degrees of knee flexion in the mentioned studies: in 2014, Dietrich et al could show a significant increase of TTTG distance values at near extension (105). Furthermore, in the same year, Izadpanah et al could find a correlation between changes of TTTG distance when weight bearing in full extension (106). Nevertheless, a pathologic TTTG distance is found in 56% of patients with PFI and therefore should be considered an important diagnostic tool (19).

1.3 Diagnosis

Patellofemoral instability shows quite a big range of variation in symptoms and severities and may go along with patellofemoral dysfunction and pain. Interplays between several dysfunctional anatomical structures are usually the causal factors provoking PFI. For this reason, an extensive diagnostic scheme has to be performed in order to comprehend the individual malfunction and initiate proper therapy (6) (11).

An etiological distinction between different forms of PFI has to be made. For a general categorization, it is possible to differentiate traumatic (primary) dislocation and recurrent dislocation as the most impressive and treatment-worthy expressions of PFI. In contrary to primary traumatic dislocation, recurrent dislocation (and the precursor subluxation) are more often associated with predisposing anatomical deficiencies. However, primary dislocation may subsequently lead to recurrent dislocation and for this reason a sound anamnesis is crucial. Additionally, aside from the clear presentation of actual patellar dislocation (see Figure A) other patellofemoral joint disorders can show unspecific symptoms such as swelling, crepitus and peripatellar pain and might complicate diagnosis (6) (17) (39) (107). Besides clinical and radiological diagnosis, arthroscopy is an important part of initial assessment of primary dislocation in order to evaluate the joint situation directly and to decide further steps of treatment (17).

Figure A. Clinical presentation of patellar dislocation of the right knee.

1.3.1 Primary Dislocation / Recurrent Dislocation

Patients with acute primary patellar dislocation usually report a typical triggering mechanism such as a sports injury. Therefore, the patients are usually young, healthy and active; the dislocation mostly occurs out of physical overstrains or collisions and the reason needs not be an underlying patellofemoral pathology (17) (108). Diagnosis is easy as the patients present with pain and stay in a relieving posture with the affected knee flexed. The medial femoral condyle can be palpated as the patella's position is shifted laterally (17). However, diagnosis is more complicated in patients reporting subluxation or dislocation with spontaneous relocation. In those cases, the etiology is unclear and the patients usually do not present with explicit symptoms (107). Therefore it is important to perform solid anamnesis about whether a traumatic or a non-traumatic event was the triggering mechanism. Sometimes, patients might even have a long history of uncomplicated subluxation tendencies. Young patients less than 14 years of age with symptoms of instability in both knees should be noticed in particular, as osseous deficiencies are mostly responsible for this kind of recurrence (17). Additionally, it should be kept in mind that some risk factors for PFI can be inherited and thus it is important to take family anamnesis in order to gain directive information (17) (109) (110).

1.3.2 Clinical Assessment of PFI

1.3.2.1 Evaluation of the standing patient (axes, laxity, torsion/rotation)

The physical examination of a patient presenting PFI should consist of several parts. According to a scheme proposed by Pagenstert and Bachmann (2008), the first part is performed with the patient standing upright, with both knees fully extended and feet placed parallel (111). Any malalignment of the leg axis should be observed (genu varus, valgus, recurvatum, antecurvatum). In particular, valgus and recurvatum alignment are considered an important factor in PFI. Valgus alignment leads to increase of Q-angle values (see 1.2.7.1) and is therefore more often associated with patellofemoral dysfunction than varus alignment; recurvatum alignment is often found in patients with tissue laxity, which in turn is correlated with patella alta (see 1.2.5) and might cause PFI (6) (11) (19) (111) (112).

Tissue laxity could also blur the evaluation of PFI as patients with articular hypermobility tend to show less symptoms of chondral injury after acute primary patellar dislocation compared to patients with normal mobility (113). Beighton et al (1973) described a method for evaluating general articular mobility. By assigning points for each positive of the following tests, a rating scale from 0-9 could be established: 1 point for each passive dorsiflexion of the small fingers > 90°, 1 point for each thumb passively bent until it touches the flexors of the forearm, 1 point for each hyperextension of the elbows > 10°, 1 point for each hyperextension of the knees > 10°, 1 single point for being able to bend the upper body with knee extended and touching the floor with both hands flat (111) (114). Another aspect is the internal rotation of the patellofemoral joint as malrotation was described being another factor in patients with PFI (19). Increased femoral antetorsion leads to internal rotation of the femur and thereby the patella tends to point inwards; likewise, external tibial rotation might produce the same phenomenon as the patient needs to rotate the tibia internally during locomotion in order to keep a sufficient and physiological rolling of the foot. Those malrotations produce a “squinting” patella together with an internally rotated patellofemoral joint. As a result, the Q-angle increases significantly and is conjoined with occurrence of higher forces in the joint. (111) (115). With the patient still standing, Pagenstert and Bachmann point out the importance of evaluating not only the leg axis but also to concentrate on the ankle joint and the feet. An excessive varus constellation in the knee mostly produces overpronation of the foot – the result is an internal rotation of the tibia and knee – with the previously described downsides (20). Hence, patellar conduction and bad tracking is often not only a problem concerned with and caused by the knee but is also in close correlation to foot malpositioning (111).

1.3.2.2 Evaluation of the moving patient (intoeing, patellar glide, crepitation)

In the next part, the dynamic situation of the knee will be assessed. The patient’s natural gait pattern is observed for restrictive or pain avoiding movements. Special focus should be placed on “intoeing”, a form of movement where the feet point inward while walking. This phenomenon occurs frequently in children but usually resolves during growth. If intoeing persists in adolescents however, it may be connected with increased internal tibial rotation and thus should be considered a significant deviation of the physiological gait pattern

(116). Furthermore, active external rotation of the limbs during walking could be caused as a reaction to excessive internal rotation of the femur (17). The next step should be to watch the patellar movement during flexion; therefore, the patient needs to squat as deep as possible and stand up again. Patients with PFI or other patellofemoral syndromes sometimes show a rugged patellar movement instead of smooth gliding. Eventually, crepitation during movement can be heard. On the one hand, this might be caused by a dysplastic trochlea or eventually by a hypertrophic plica, but on the other hand, crepitation could also be idiopathic and not linked to any morphological dysfunction (111). Additionally, no correlation could be found between pain and crepitation; besides, crepitation occurs in 94% of healthy women and in 45% of healthy men (117).

1.3.2.3 Evaluation of the sitting patient (patella alta, quadriceps deficiency, J-sign)

After that, further examination is performed with the patient sitting, both feet hanging freely and a knee angle held in about 90° with the quadriceps slightly contracted. For a start, patellar position should be evaluated. Usually, severe patella alta position (see 1.2.5) is a prominent malposition which can be observed as the patella lying on the femur instead of the trochlear groove and thus pointing upwards instead of forwards; sometimes it might even point to the ceiling (111). If a high-riding patella cannot be seen on first sight, another accompanying sign might come in handy: if the kneecaps point outwards and upwards ("grasshopper eyes"), this position could be correlated to patella alta (111) (118). Furthermore, the muscular situation needs to be assessed. In normal patients, the contracting VMO should appear as a prominent bulge which is decreased in patients with VMO dysplasia or atrophy (111). According to Senavongse and Amis (2005), the effect of muscular deficiency leads to increased lateral patellar shift during contraction and might even favor subluxation, which could be observed in clinical investigation evidently (45). Furthermore, the appearance of the so called J-sign should be observed. This sign is an assessment of the dynamic patellar glide during active extension of the knee. As the name suggests, the J-sign is positive if the patella does not follow a straight path along the trochlear groove but rather forms an inverted J-like deviation in near extension. In reverse order, the "reversed J-sign" might occur and can be found in patients with more severe osseous malformation (17). Although no exact data for association between the J-sign and PFI is established, some authors could find no - or at least less - occurrence of the J-sign in patients without symptoms of PFI; therefore, the J-sign can be considered a valuable reference (17) (111) (119) (117).

1.3.2.4 Evaluation of the lying patient (tests in supine and prone position)

Supine position

This part of examination is the most extensive and includes several tests that give clear and impressive predications on contributing factors in PFI. With the patient lying supine it is possible to further assess potential patella alta by identification of the "camelback - sign" in about 30° of knee flexion (118). Observing the knee from a lateral position, this sign appears as the Hoffa's fat pad bulges out the skin in the position where the patella would usually lie. The second bulge is formed by the patella itself lying more proximally, this results in a picture resembling a camel's back (111) (118).

Of course, every standard physical examination includes palpation for peripatellar tenderness and assessment of knee joint restriction by testing the full range of motion. Particularly in regard to detection of injury or overstraining, joint swelling and intraarticular effusion should be evaluated. In a joint with excessive intraarticular fluid, the patella does not interact with the femoral trochlea but rather floats above it. Therefore, when applying rather perpendicular pressure on the patella, the examiner might feel the patella tapping on the femoral trochlea. This indicates intraarticular fluid of about 50 ml (111). Additionally, the examiner can put some pressure on the patella in different degrees of flexion in order to reveal patellofemoral arthrosis (111). The Clarke sign could also provide information about the patellofemoral condition. With the fully extended knee and quadriceps relaxed, the examiner pushes the patella distally by placing the hand on the suprapatellar field and putting some pressure on it. With maintained pressure, the patient should now contract the quadriceps. In case of patellofemoral arthrosis, this test leads to retropatellar pain during contraction (111). However, the diagnostic value of the Clarke-sign is not clear as it seems to be rather unspecific. Doberstein et al (2008) could not find a correlation between patellar chondromalacia and the Clarke sign and even suggest excluding this test as a routine part of knee examination (120).

Pagenstert and Bachmann (2008) described a sophisticated scheme of tests for evaluating patients with patellofemoral problems; however, the apprehension test clearly dominates in terms of specificity for assessment of PFI and will therefore be described further. Already in 1937, Fairbank described a fear of dislocation and reactive quadriceps contraction in patients if the examiner pushes the patella manually in lateral direction (111) (121). Based on this information, Hughston (1968) established a guideline for assessing this apprehension by applying lateral force in 30° flexion with the quadriceps relaxed (111) (118). Usually, the patients immediately report a strange feeling and a fear of dislocation. In order to keep the patella tracking along the groove some even start contracting the quadriceps. Schoettle et al (2009) pointed out the importance of correct and empathic practical application of this test especially in pediatric patients. They propose to support the outer side of the patella with the other hand in order to give patients with distinctive apprehension a secure feeling (17). The apprehension test is a remarkable test as it does not only distinguish between positive or negative PFI but also gives a clue which structure might be affiliated. Therefore, the test should be performed not only in 30° flexion but also in full extension, 60° and 90°. A positive apprehension in between full extension and 30° flexion might be connected with dysfunction of passive structures, while apprehension in higher degrees of flexion usually appears due to static, osseous malformation such as trochlear dysplasia or axis malalignment (17) (45).

The next test tries to evaluate the lateral passive structures and their tightness (122). With the quadriceps relaxed and the knee fully extended the examiners thumb tries to lift the lateral patellar portion away from the lateral femoral condyle. The referential axis of the passive patellar tilt test is the floor: negative values or values corresponding with the referential axis implicate excessively tight lateral structures. However, this value is gender-specific and a study by Tomsich et al (1996) showed that men generally tend to show lower passive patellar tilt values (111) (123). In order to evaluate the biomechanical condition of those passive structures further, Kolowich et al (1990) proposed to quantify medial and lateral patellar glide (122). Therefore, the patella is sectioned by three longitudinal lines, generating four patellar quadrants. While the examiner pushes the patella in lateral and medial directions, the extent of displacement is identified by the amount of quadrant-gliding: lateral glide of three quadrants or more indicate insufficiency of medial retinacular restraints such as the MPFL, while medial glide of one quadrant or less is related to excessively tight lateral restraints (111) (122).

Although measurement of the Q-angle still is still part of diagnostics as it is connoted with higher joint forces (111) (115), the association with lateral patellofemoral translation is not clear and therefore cautious weighting or even general omission is advised (98).

Prone position – detection of malrotation and muscular contraction

In the prone position it is possible to evaluate malrotation and excessive muscular contraction. Both high tension of the iliotibial tractus and contraction of the rectus femoris muscle play an important role in patellofemoral biomechanics. While it is possible to palpate a tight iliotibial tractus directly at the area of the lateral femoral condyle, an excessive rectus contraction results in increased distance between heels and buttocks (17) (124). For testing this distance correctly, both sacroiliac joint and knee joint need to be fixed in order not to provoke external rotation of the hip. In normal patients, the examiner bends the patient's knee without a big restraint and the heels touch the buttocks. In patients with rectus contraction, this distance might be increased (17).

Staheli et al (1985) described normal values of rotation in the lower extremities in order to detect malrotation in clinical evaluation. Accordingly, the following range was regarded being physiological in males and females (111) (125):

- Internal hip rotation: 25-65° ♂/ 15-60° ♀
- External hip rotation: both genders 25-65°

Both rotations are measured in supine position, with the knee flexed 90°. Thereby, the tibia becomes an axis which is referred to an axis constructed perpendicular to the horizontal floor. Usually external rotation can be performed easier; normal patients rotate externally about 30° more than internally (111). Deviations of the normal values implicate malrotation, mostly caused by increased femoral antetorsion in patients with PFI.

1.3.3 Radiological assessment of PFI

For complete diagnosis of patellofemoral disorders imaging is mandatory. If a patient presents with symptoms of PFI, regardless of acute or recurrent onset, the first step should be radiographic evaluation of the knee in order to assess patellar position and osseous deformation, dysplasia, fissures or fractures (126). Furthermore, CT imaging was described being a valuable method for assessing various co-factors of PFI, such as aberrant force vectors and malrotation; even the examination of the leg axis and the biomechanical relationship and torsion measurement of all structures in between the femoral head and the ankle joint might be included in a long leg view (17) (127). However, the MRI offers the best synopsis of the patellofemoral joint, including the state of soft-tissue and cartilaginous structures and therefore is method of choice in patients with unspecific patellofemoral symptoms (see Figure B) (126) .

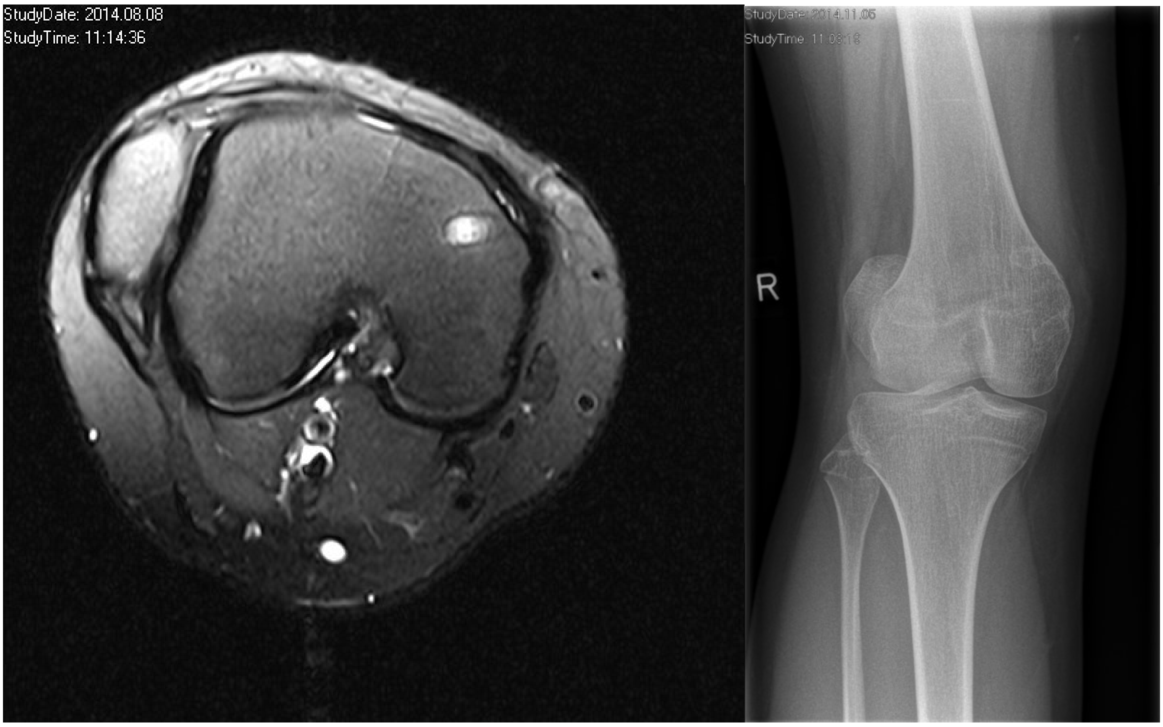


Figure B. Although radiographs offer valid information about the general condition of the knee, MRI is an excellent tool in order to assess the patellofemoral joint more in detail.

1.3.3.1 Radiography

The standard radiographic investigations for evaluation of the osseous structures of the knee joint are a.p. and lateral imaging. The main focus lies on assessing patellar position in the knee joint and detection of osseous degeneration, dysplasia, fractures and ligament/bone avulsions. Usually, the a.p image is performed with the patient standing. The degree of flexion varies in the lateral image, depending on the need for assessing patellar height and the therefore chosen testing method (Patella alta and measuring methods see 1.2.5). In any case, the lateral radiograph should be taken with both femoral condyles superimposed (crossing sign; trochlear dysplasia, assessment and classification see 1.2.3) (127). Diagnosis of patellar fracture might be complicated in not yet ossified patellas of adolescents or patella partita. Kramer et al (2008) therefore propose to closely check the questionable fracture borders: in patients without fracture, those borders usually appear smooth (126).

In addition to the standard radiographs several shooting techniques especially for diagnosing PFI have been described. The most important technique to assess the patellofemoral joint is the tangential image of the patella in 30°- 60° flexion (17) (127). With this method it is possible to evaluate the relationship between the patella and its underlying trochlea and estimate the grade of trochlear dysplasia by measuring the sulcus angle (46) (47). Furthermore it is possible to diagnose retropatellar arthrosis, dysplasia and osteochondrosis dissecans. Additionally, this method shows excessive patellar tilt (assessment and evaluation see 1.2.6.1) or decentralized position of the patella (127). To assess patellar glide, Pietsch et al (2006) proposed to assess a functional dynamic image in 30° flexion with the quadriceps fully contracted and the tibia completely rotated externally; this is a preferred method in comparison to sunrise views in 30°, 60° and 90° of knee flexion (127). With this method, lateral patellar shift can be measured and should be less than 5 millimeters (128). The following table 1 shows a summary of possible diagnostic possibilities concerning PFI in radiography (17) (48) (126) (127) (128):

a.p. view	Lateral view	Strictly lateral view	Tangential view
- Fractures *- Avulsion* *- Necrosis* *- Leg axis**	*- Fractures* *- Avulsion* *- Patellar height (Patella alta)*	*- Trochlear morphology (Trochlear dysplasia)* *- Patellar hypoplasia*	*- Retropatellar arthrosis* *- Osteochondrosis dissecans* *- Patellar shift/glide***

Table 1

**only in long leg views (see Figure C)*

***only in dynamic imaging (30° flexion, quadriceps contracted, tibia rotated externally)*

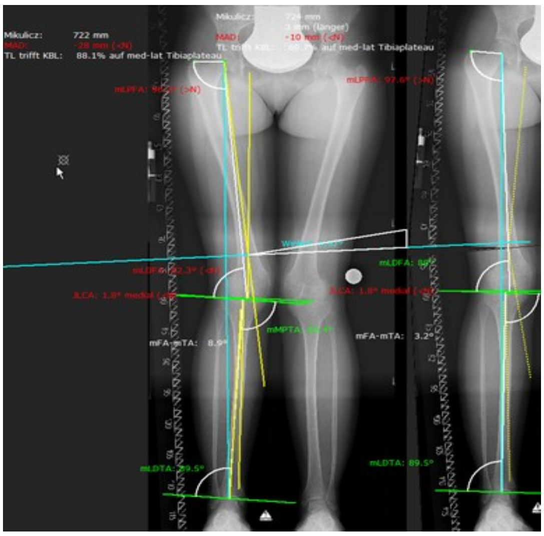


Figure C.

The long leg view offers relevant information about the biomechanics of the leg and allows calculating the leg axis.

1.3.3.1 CT

By the use of CT it is possible to further investigate and complete the assessment of the main factors correlated with PFI, which were proposed by Dejour H. (19). As the patellar height was already measured and first steps for diagnosis of trochlear dysplasia and patellar tilt have been performed by the use of radiographs, the next steps are, on the one hand, confirmation of the gathered information and on the other hand, the evaluation of patellar malalignment by measuring the TTTG distance. (Q-angle and TTTG distance see 1.2.7) Because the TTTG distance is a static value, Pietsch et al (2006) pointed out the limited information concerning the dynamic components such as patellar tilt and subluxation (127). However, it is possible to assess the factors of VMO-dysplasia and those involved dynamic instability factors by the use of CT. Several methods for assessing the patellar tilt have been described (Patellar tilt see 1.2.6.1). Nevertheless, patellofemoral tracking abnormalities can be revealed in CT and usually a diagnosis can be established in synopsis with clinical findings. In this context, Schutzer et al (1986) distinguished patellofemoral maltracking into three entities: subluxation, tilting and subluxation or solitary tilting. (127) (129).

Some authors also consider the use of extensive axial CT scans in order to evaluate a pathologic leg-axis and to detect the secondary contributing factors of PFI like rotational malalignment, femoral torsion, rotation of the knee and tibial torsion (17) (130). However, especially in pediatric patients, CT scanning has to be considered an unnecessary exposure to radiation which should be avoided by restrictive and critical indication (127).

1.3.3.2 MRI

The MRI inherits the diagnostic power of CT scans and even takes it further. Regardless of the obvious advantages concerning exposure to radiation, the MRI offers valuable information about the contact surfaces, the patellar glide and cartilaginous condition; therefore it is proposed as method of choice in diagnosing patients with symptoms of PFI (126) (127) (131). On MR - images it is possible to adopt the CT - methods for evaluating the patellofemoral joint. According to Schoettle et al (2006), measurement of the TTTG - distance seems to be highly reliable in MRI, as the examiners can easily identify leading structures. Additionally, it is possible to evaluate malrotation of the lower extremities very precisely and therefore the use of CT as gold-standard has to be reconsidered (82) (100) (132). Especially in patients with unclear recurrent symptoms of PFI, the MRI detects latent structural damage such as bone bruises and subchondral edema in the patella. Usually, the lateral femoral epicondyle and the medial patellar facet are the most affected structures (9) (126). Apart from this, acute traumatic damage of cartilaginous and bony structures such as flake fractures caused by dislocation can be diagnosed explicitly (126).

However, the biggest advantage of MRI lies in evaluation of soft-tissue (see Figure D). Therefore, as the passive structures are an important factor in patellofemoral stability (structural weakness and deficiency of passive restraints see 1.2.2) the use of MRI is recommended. Of all the retinaculae connected with the patella and securing its position, the MPFL is the most important structure. In MRI, this ligament is part of the medial retinacular complex and thus sometimes difficult to encounter (126). The MFPL usually ruptures after complete acute lateral dislocation and therefore, besides hemarthrosis, it is regarded a definite proof to encounter this ligament torn (9) (11). Elias et al (2002) defined partial rupture and rupture of the MPFL as either partial discontinuity of the fibers or complete absence of fibers with concomitant surrounding edema (9).

Apparently, the exposure to radiation could be decreased drastically by introducing an individually aligned combination of radiographs and MRI for assessing patients with PFI. Even patellar tracking might be evaluated by the means of dynamic MRI. This is an impressive step in understanding the biomechanics of the patellofemoral joint and first results seem promising (133). After all, MRI already is a valuable tool in diagnostics of PFI and could replace CT-investigation, especially in pediatric patients (82).

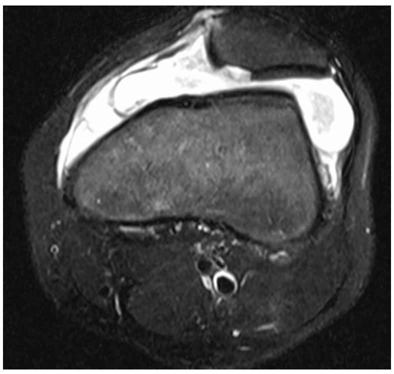


Figure D.

Evaluation of soft tissue and cartilage is the biggest advantage of MRI. Those images show a torn MPFL and cartilage defect in the patella surface.

1.3.3.3 Sonography

A simple tool for assessing intraarticular effusion and bony fragments after acute primary dislocation is sonography (127). Parsch K. (2002) also focused on diagnosing congenital knee dislocation in children and showed remarkable results. The image-quality was described to be equal to MRI. Parsch furthermore describes the use of sonography as a golden standard for primary diagnosis, classification and follow-up after conservative treatment of congenital knee dislocation. Compared to the costs of MRI, the use of sonography for assessing recurrent PFI should be considered as it is a fast and unpretentious, yet effective tool (127) (134).

1.4 Treatment

The treatment options for PFI vary widely and while there exists a -more or less- consensus for conservative methods, no standardized procedures and gold standards exist in regard to operative treatment (6). This might be due to the broad range of diverse influencing factors and etiologies. Although some of the published methods for treatment of PFI seem promising, none could show overwhelming results; this suggests, that the pathomechanisms have not yet been understood completely (17). Additionally, some of the historically used methods (such as the isolated lateral release) have now been revised while others try to take their place (135). Therefore, to initiate adequate therapy, an extensive investigation of the individual factors of PFI needs to be performed. Out of the pool of numerous techniques, conservatively as well as operatively, the decision has to be based on (115):

- age and skeletal maturity,
- causing factors and the history of PFI
- the patient's general muscular condition / level of activity.

Of course the grade of injury and condition of the articular surface is another big contributing factor that often gives helpful directives in regard to the initial therapy of patients presenting after acute dislocation: severe effusion, loose bodies and retinacular injuries are usually treated operatively (6) (115). However, most of the cases of primary dislocation could initially be treated conservatively. Nevertheless it is important to consider that those patients show a tendency to develop recurrence of PFI (136) (137). In conclusion, there still exists ambiguity about the ideal therapy of primary patellar dislocation (137).

1.4.1 Initial treatment of acute patellar dislocation

In some cases, especially in patients with recurrent instability, the patella already relocated at the time of hospitalization. However, patients with persisting dislocation of the patella usually present with severe pain and the knee held in a flexed position while the patella is found displaced laterally (17). For patellar relocation the knee should be re-extended, while adequate analgesia and sedation should keep the pain on bearable levels. During passive extension, it is important to hinder the patella of uncontrolled snapping back into the trochlear groove as this movement could cause additional cartilage damage especially on the lateral femoral condyle. Therefore, the patella should be detained manually in its lateral position and then gently and gradually released (17) (138). Furthermore, as part of first-aid treatment of soft tissue injuries, the RICE scheme (Rest, Ice, Compression, Elevation) should be applied in order to stop injury induced bleeding, swelling and thereby minimize discomfort (139). Aspiration of excessive hemarthrosis and effusion is also an option to support recovery (6) (136). If there are no signs of fracture in radiographic evaluation, the knee should be kept in 20° flexion and be immobilized for about a week; further assessment and MRI should be performed within two weeks after dislocation (17) (136).

1.4.2 Conservative treatment

Sillanpaa and Maenpaa (2012) described a treatment algorithm for assessing patients with primary patellar dislocation. According to this scheme, patients without fractures and the possibility of active flexion and extension with a stable patella should initially be treated conservatively. Furthermore, they regard following situations as eligible for conservative treatment: partial MPFL injury, MPFL disruption at the femoral attachment and MPFL disruption at the patellar attachment if no articular cartilage damage is involved; however, those recommendations imply a joint without severe dysplasia (136). If conservative treatment is chosen - after a short period of immobilization - the patient needs to regain mobility as fast as possible in order to prevent stiffness (6). According to Schoettle et al (2009), a five week period of limited movement in a hard frame orthosis should be arranged after an initial week of immobilization in 20° flexion (17). Flexion can be increased from 60° up to 90° in this period, while extension and the therewith associated lack of osseous guidance should strictly be avoided in order to give the torn retinacular structures a chance to heal. They furthermore mentioned that the MPFL should have recovered so far as that a slight functional stability should be restored and apprehension is negative after six weeks in total. The examination after six weeks contributes valuable information about the condition of the joint and offers the possibility of reconsidering conservative therapy. In cases of severe underlying joint malformation, the apprehension test might be positive and therefore operative treatment should be taken into account. However, if the knee appears to be stable, the next steps of activation should be initiated in agreement with tolerable pain and after six more weeks of therapy the capability to return to sports should be restored according to Schoettle et al (17). The principles of conservative therapy lie in restoring the function of the dynamic patellar restraints as it is connoted with the best long term outcome (136). Physical therapy addresses quadriceps and gluteal muscles with functionally strengthening exercises, restores the range of motion, and helps the patient to regain a good proprioception in the knee (6) (136). Especially close chained exercises seem to have the biggest effect on the quadriceps, as they initiate a balanced activation of the whole muscle (140). Taping as part of physical therapy is not yet completely established. On the one hand it increases muscular torque of the quadriceps and initiates earlier activation of the VMO, on the other hand it is important not to initiate physical therapy too early assuming that taping stabilizes patellar tracking: studies have shown that taping has no significant effect on lateralization (6) (141).

1.4.3 Operative treatment

If conservative treatment fails or the initial patellofemoral injury is too severe – indicated by occurrence of fractures, cartilaginous injury or loose intraarticular bodies (flakes, see Figure E on the next page) - operative treatment is the next logical step (17) (142). Also in reference to the high rate of redislocation after conservative treatment, operative treatment might be indicated in order to prevent unnecessary pain and additional damage to the joint (136) (137). Several methods trying to address the various factors causing instability in the patellofemoral joint have been described; however, still no method seems to be considered as a golden standard (6) (17) (115). Especially the lack of skeletal maturity in pediatric patients requires sophisticated surgery, focusing on soft tissue procedures rather than osseous techniques (143). The credo for all operative methods for PFI should be the establishment of a pain-free physiological joint movement and biomechanically stable patellar tracking.

Figure E: An osteochondral flake after primary patellar dislocation indicates severe injury and requires adequate surgical treatment.

1.4.3.1 Lateral release

In the past, lateral release (including the lateral retinaculum, vastus lateralis obliquus muscle and the distal patellotibial band) was described to be an effective therapy for patellar tilt (39) (122) (144). However, it was recognized that release of the vastus lateralis obliquus - a muscle that apparently showed to generate important lateral force vectors on the patella – does not essentially decrease patellar instability (39) (144). Nowadays, the importance of isolated lateral release for treating PFI has been pushed back even further and only plays a role in managing a lateral patellar compression syndrome (6) (122). Even more, isolated lateral release yields unacceptable results in terms of patient satisfaction and long term outcome; studies even report of a 100% rate of redislocation (122). Additionally, a cadaveric study by Christoforakis et al (2006) could impressively demonstrate the disadvantageous effects of lateral release for treatment of PFI: apparently, the required force to displace the patella laterally is reduced significantly after lateral retinacular release (145). Therefore, this procedure only finds it value only in treatment of tight lateral structures and should be combined with medial sided procedures such as medial reefing or MPFL repair (see 1.4.3.2 and 1.4.3.5) (6) (146) (147).

1.4.3.2 Medial capsule reefing

Controversy exists in evaluation of medial capsular reefing as an effective method to bridle an unstable patella. As well as diverse nomenclature for this procedure was described, also the surgical techniques and postoperative evaluation methodology differ widely. In a systematic review, Cerciello et al (2014) found all possibilities of invasiveness, spreading from arthroscopic to open techniques. Additionally, some authors include the lateral release and tibial tubercle transfer (see 1.4.3.1 and 1.4.3.3) as part of the treatment for PFI. This confusion in literature and the fact that most of the available studies are case studies makes it hard to give an ultimate statement regarding efficacy of medial capsule reefing (148). However, there is a fairly general agreement on a positive outcome of this procedure in most of the cases, even at long-term follow up. Lee et al (2012) could report of a low redislocation rate of 3 in 31 patients after a quite long follow up of 11.6 ± 2.4 years with a combination of lateral release and medial reefing (149). An important observation was made by Schoettle et al in 2006: apparently, medial reefing is a reliable method as long as the trochlea is not severely dysplastic. Patients with trochlear dysplasia of grade B and higher have shown a significantly worse outcome within 12 months, with redislocation in 4 out of 22 knees compared to no dislocation in 26 knees with dysplasia grade A or less (150).

The idea of medial reefing is that a tighter patellar re-attachment of medial retinacular and muscular structures should hinder the patella in dislocating laterally. However, Fulkerson (2002) advises not to overstrain this procedure and keep the patellar glide balanced on the physiological tracking route. Otherwise, if the reefing results in excessively tight structures, patellofemoral pressure increases and this might lead to chronic cartilage damage (151) . Colvin and West (2008) substantiate this warning and describe the medial reefing as a non-anatomical procedure which could result in over-medialization and abnormal tracking of the patella (6). Furthermore, Ostermeier et al. (2007) described the kinematics of a knee treated with lateral release and medial reefing. Hence, compared to the patient's healthy counterpart knee, increased tilting and medialization during movement occurred (152).

In conclusion, medial reefing is an integral part of PFI treatment; however, literature delivers confusing guidelines and methods. Therefore, further regulated studies are needed in order to establish a sophisticated appraisement for this method.

1.4.3.3 Tibial tubercle transfer

As mentioned in chapter 1.2.7.2, increased TTTG distance is a factor correlated with PFI. Dejour et al (1994) established a threshold value for this distance of 20 millimeters (19). A method for distal re-alignment of patellofemoral malalignment is the tibial tubercle transfer. By transferring the tibial tubercle, this method reduces the distance of the tuberosity to the sulcus to normal values and thereby tries to establish a physiologic quadriceps pull vector, resulting in stabilized patellar tracking (153). Several methods for this transfer have been described, which still remain popular and yield good results in regard to correcting malalignment and pain (6) (154). The Elmslie-Trillat procedure and anteromedialization of the tibial tubercle are common methods and have been investigated thoroughly (154) (155) (156). Nakagawa et al (2002) observed the outcome of 10 year follow ups in patients with recurrent dislocation treated with the Elmslie-Trillat procedure and found six re-dislocations in 45 knees. However, they state that the main deterioration after surgery was patellofemoral joint pain and not PFI (157). This already implies the big risk of tibial tubercle transfer: overmedialization of the tibial tubercle increases patellofemoral contact pressure and additionally strains the medial tibiofemoral joint. For this reason, Kuroda et al (2001) recommends to be especially cautious in patients with varus knee alignment, after meniscectomy and arthritis in the medial tibiofemoral compartment (158). In 2014, Wang et al presented satisfactory and long lasting results in patients treated with a triple positioning technique. They describe this technique as suitable for optimizing the patellofemoral malalignment: by combining anterior, medial and proximal transfer of the tubercle, this method regulates predominant patellar tilt, excessive patellofemoral compression, a tight patellofemoral joint and patella baja (159).

In combination with other surgical options, the tibial tubercle transfer is a method which is indicated in patients with an excessive TTTG distance; however, side-effects such as increased patellofemoral pressure, patellotibial pressure and pain should not be left unmentioned.

1.4.3.4 Trochleoplasty

Trochlear dysplasia is one of the most important underlying factors of PFI and is regarded as the number one joint pathology that leads to failure of treatment. In order to establish a better engagement with the patella, the dysplastic and often prominent trochlea is rearranged in order to create a more anatomical groove. Moving space for the cortical bone is created by removing underlying cancellous bone and thus the trochlea can be repositioned in a way that a sulcus is formed (6) (53). Nelitz et al (2012) examined 37 adolescent patients and found a 89 % rate of trochlear dysplasia (B-D) in those who had an unsatisfactory outcome after surgery (160). For this reason, repair of trochlear dysplasia apparently addresses the major underlying pathology for PFI and should yield valuable results. Studies could demonstrate that trochleoplasty can rearrange the trochlear groove and establish a fairly normal anatomy, showing good results in regard to re-dislocation. Nevertheless, there is not yet sufficient data in order to evaluate this surgery properly (81) (161). On the other hand, Colvin and West (2008) report of ambivalent results and even speak of restricted use in the United States due to the risk of causing serious and irreversible joint damage (6). Especially children with still widely opened growth plates in the distal femoral physis are unsuitable for this procedure (160).
Nevertheless, the first steps into genuinely treating recurrent PFI have definitely been done by addressing the main pathology. Especially encouraging seems a combination of MPFL repair (see 1.4.3.5) and sulcus deepening trochleoplasty, reported as being a safe and reproducible procedure with a good patient satisfaction (162). Trochleoplasty is a demanding procedure and techniques still have to be developed further; also the existing equivocal opinions have to be resolved in order to establish this method. However, it should be kept in mind that trochleoplasty goes along with the big disadvantage of limited usability in pediatric patients.

1.4.3.5 Reconstruction of the MPFL

The MPFL as part of the passive medial structures takes an important part in preventing patellar dislocation and aids patellar tracking and stability especially in lesser degrees of flexion. Dislocation mostly leads to rupture of the MPFL and therefore the next logical step in restoring patellar stability is its reconstruction. A big advantage of this operation is the applicability in pediatric patients, as mostly passive structures are manipulated and osseous involvement affects safe areas only. Nevertheless, drilling holes could eventually impair open growth plates and therefore it is essential to be especially cautious, particularly on the femoral site. Due to this restriction, pediatric MPFL reconstruction is described being a bit more non-anatomical in comparison to the rather same technique in adults (163). Depending on the PFI and mechanism of injury, several possible techniques for reconstruction have been described. In case of primary dislocation and accompanying rupture, the MPFL can be reattached either by suture or suture anchor design on the respective (femoral or patellar) site of avulsion (17). However, the quintessence of all described techniques for treatment of recurrent PFI is the MPFL reconstruction by using an autologous gracilis or semitendinosus tendon, re-attached as far as possible in the former physiological style of MPFL insertion (17) (164) (165). Since reconstruction of the MPFL is a relatively new method, there is no final consensus about the ideal technique. Colvin and West (2008) found differences in choice of graft, graft positioning, graft tension and static versus dynamic reconstruction. Despite those controversies, the results are encouraging and MPFL reconstruction already seems to beat tibial tuberosity transfer regarding stabilized patellar movement; however, some patients benefit from a combination of both methods (6) (166). An important negative consequence of this operation might be overuse of the medial patellofemoral cartilage due to an excessively tight graft. Additionally, patients with preexisting chondromalacia patellae seem to have a worse outcome and therefore only patients without major changes in patellar cartilage seem to be suitable for this operation (6) (101). The biggest restriction of this method is PFI in combination with a high grade trochlear dysplasia. Although the reconstruction in patients with A and B dysplasia is already a common method, more severe stages drastically decrease the positive outcome and therefore some authors prefer not to trust in this operation alone (166).

2 Patients and Methods

2.1 Hypothesis and purpose of the study

As the introduction part already showed, the ideal treatment of patients with PFI has been discussed widely. Several surgical methods have been proposed but none of them could be established as a gold standard. The diversity of described treatment options only points out the lack of profound understanding of this complex pathology. Many factors seem to play a major role in the development of PFI and therefore a correct treatment should, at best, address all of them. For adults, the research has made a good progress and after a phase of trial and error, the treatment options seem to improve constantly. However, pediatric patients offer a more challenging situation. Due to the skeletal immaturity, some of the therapies used for adult patients are not suitable for children. For this reason, treatment of PFI in children focuses on soft-tissue procedures. One of the possible options is the reconstruction of the MPFL by using an autologous semitendinosus or gracilis tendon. This ligament plays a major role in the stabilization of the patella, and its reconstruction has already showed encouraging results for the treatment of PFI in adult patients. In order to aid the search for an ideal treatment, this study investigates the outcome of isolated MPFL reconstruction and MPFL reconstruction combined with tibial tuberosity transfer in pediatric patients between the ages 14 and 18. The hypothesis was that MPFL reconstruction is a suitable method for treating PFI in skeletally immature patients. In order to comply with this hypothesis, following requirements had to be fulfilled:

- No further redislocation
- No further subluxation
- Improved values in Kujala's anterior knee pain score and Tegner activity score
- Subjective patient satisfaction and their theoretical will to re-perform this surgery in case PFI would occur in the contralateral knee.

Additionally, by comparing preoperative to postoperative radiographs, patella alta and trochlear dysplasia were assessed and the changes of patellar height after MPFL reconstruction were evaluated.

2.2 Patients

Assessment of potentially eligible patients was performed by searching available data of patients treated with MPFL surgery until the end of 2013 in the openMedocs database of the University Hospital of Graz. The search yielded 54 male and female patients who underwent MPFL surgery due to recurrent instability or primary dislocation at ages between 14 and 18. Recruitment was performed by telephone enquiry, based on the available contact details. Furthermore, an appointment for the follow-up examination including study-specific surveys and radiographs was arranged to take place in the pediatric surgery ambulance of the University Hospital of Graz. Besides the already mentioned inclusion criterion of patients being not younger than 14 years and not older than 18 years of age at the time of surgery, the parent's consent had to be obtained for the follow-up examination in case the patient was younger than 18 years of age at this time. Another criterion for inclusion was that no previous operations such as ligamentous reconstructions, soft tissue reefing, osseous procedures or cartilage repairs were performed on the affected extremity. The final number of patients willing to participate in this study was 35. The others could either not be reached by telephone or were unable/unwilling to take part due to reasons like geographical distance or issues in scheduling an appointment. Nevertheless, some patients agreed to take part in the study by taking the survey by telephone. The effective number of patients who took part in this study either by telephone survey or clinical follow up was 23 (26 knees). Surgery was performed due to recurrent instability in 22 knees and due to primary dislocation in 4 knees; isolated MPFL reconstruction was performed in 18 knees while combined MPFL reconstruction and tibial tubercle transfer was the method of choice for 8 knees. The gender distribution was slightly dominated by males, with a ratio of 13 males to 10 females. All patients were assessed by a medical student in the final year of studies under supervision of a consultant doctor in pediatric orthopedics. The clinical follow up could be performed with 13 patients; the remaining patients were interviewed by telephone. The mean age at surgery was 16.1 years, ranging from 14 to 18 years. By the time of follow up, the mean age was 18.9 years, ranging from 15 to 21 years. The mean follow up time was 33 months and ranged between 11 and 61 months. Different grades of trochlear dysplasia and patellofemoral chondropathia were found in all the participating patients. 11 knees had a trochlear dysplasia Dejour grade A, 9 had a grade B and the remaining 5 had a grade C. None of them had a grade D dysplasia (see Figure E). The intraoperatively assessed chondropathia was found to be grade 1 in 11 knees, grade 2 in 8 knees, grade 3 in 6 knees and grade 4 in one knee (see Figure F).

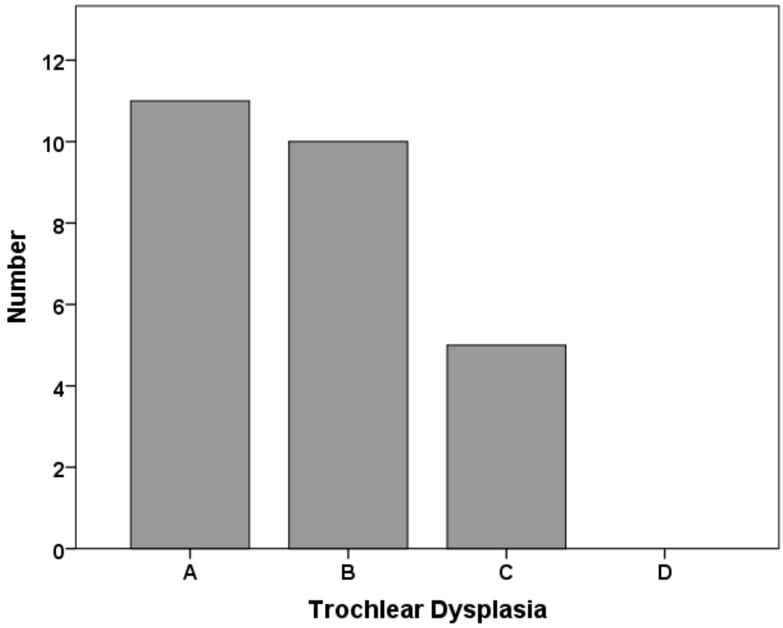


Figure E. Trochlear dysplasia was assessed by evaluating radiographs and MRI. The grading A-D was performed by focusing on indicators described by Dejour et al (52).

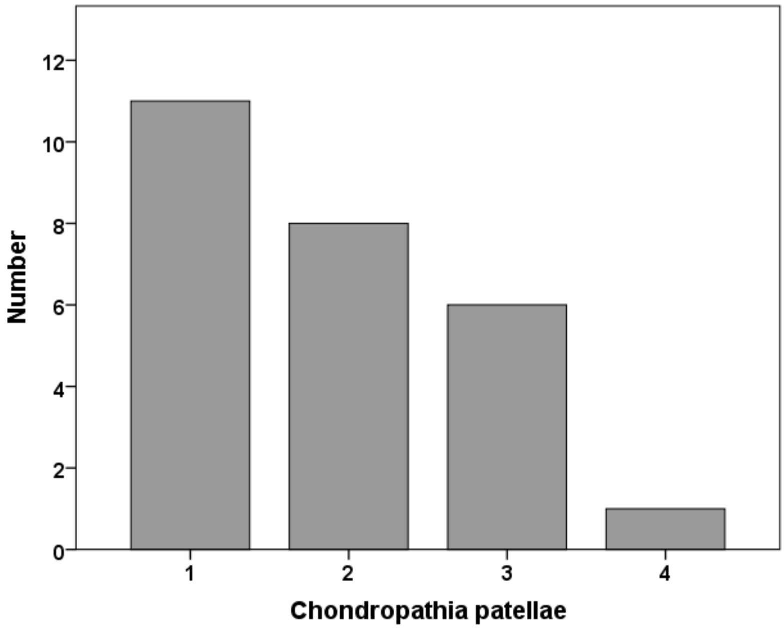


Figure F. Chondropathia was assessed intraoperatively and has been depicted from surgery reports. All patients were found to have at least grade 1 chondropathia.

2.3 Methods

This study used two approaches in order to collect relevant information. For patients who could take part in this study physically we arranged a clinical and radiological follow-up examination of the knee and asked the patients to complete two scores (Kujala's Anterior Knee Pain Score, Tegner Activity Scale, see 2.3.1 and 2.3.2) with respect to preoperative and postoperative levels in order to establish a comparison. Furthermore, the patients were asked to complete the 2000 IKDC Subjective Knee Evaluation Form (see 2.3.3) in order to appropriately assess their current post-operative follow up knee function.

Patients who were unable to take part in the study physically, the mentioned scores were assessed in a standardized scheme by telephone interview. However, pre- and postoperative radiographs were available of all patients and therefore only clinical examination was left out in those patients. Combined with available MR images the pre- and postoperative patellar heights were evaluated and trochlear dysplasia was categorized. Additional relevant patient data for the study was collected by browsing the openMedocs database of the University Hospital of Graz. By analyzing the surgery reports and evaluating intraoperative findings, the preoperative degree of chondropathia in the knee was assessed. Furthermore, recommendation for postoperative rehabilitation was depicted by those reports.

The initial standard procedure for therapy of non-severe PFI in Graz is nonsurgical. This means, that patients suffering from first time dislocations without concomitant fractures or intraarticular loose bodies are treated conservatively, predominantly with exercises strengthening the quadriceps muscle and proprioceptive exercises improving stability of the patellofemoral joint. Not until the patient develops recurrent instability, use of surgical treatment is evaluated. The technique used for MPFL reconstruction in this study was adapted from the technical note published by Schoettle et al in 2009 and will be described in the following section (167). All surgeries were performed by two consultant doctors at the University Hospital of Graz in between 2009 and 2013. The standard postoperative protocol after MPFL reconstruction is partial weight bearing from 20 kilograms to half of the patient's bodyweight for 4 weeks, supported by orthosis in a decreased range of motion of 0°- 0°- 60°. If tolerated, the patients may return to sports except for activities which include stop-and-go movements after three months. 6 months after surgery, strenuous sport in competitive levels can be resumed.

2.3.1 Surgical technique of MPFL reconstruction

The established surgical technique for MPFL reconstruction is an adaption of the proposed technique by Schoettle et al in 2009 (167). Surgery consists of two separate parts. Under anesthesia, the surgeon manually verifies the patellar instability (see Figure G, page 47) and furthermore evaluates cartilaginous condition, trochlear shape and the site of the torn MPFL by the use of arthroscopy (see Figure H, page 47). Actual reconstruction is performed in the second part. Harvesting of the gracilis tendon is performed by making a straight incision above the pes anserinus. After displaying and incising the sartorius aponeurosis, the gracilis tendon is stripped. While the tendon is being armed and muscle tissue is cleaned off, the patellar insertion gets prepared by a medial parapatellar incision. The insertion site must be prepared in a way that a bony rim or guiding channel is formed; anyway, the formed structure has to be deep enough in order to embed the harvested gracilis tendon securely with suture anchors. After that, the femoral insertion site is being prepared. The incision is made over the medial femoral condyle with the knee flexed in about 30°. The graft already attached to the patella gets pulled through the second and third layer of the knee capsule by a suture loop (see Figure I, page 48). In children with open growth plates, careful positioning of the femoral insertion is essential (see Figures J and K, page 48). Guide wire placement can be controlled and compared to preoperative planning by roentgenoscopy on lateral views. The diameter of the femoral drill hole should extend to the contralateral cortex and be 0.5 mm bigger than the two free graft ends. After controlling the correct femoral tunnel placement, the autograft can be pulled into the femoral insertion and locked with interference screws in about 30° of flexion. The full range of movement should be controlled immediately and lateral patellar dislocation should be evaluated. The ideal length and positioning of the autograft is variable; however, it is important to arrange the autograft in a near anatomical way such as the sail-like form of the original MPFL. Excessively tight reconstruction might result in decreased range of movement and pain due to increased patellofemoral pressure. On the other hand, loose reconstruction might lead to recurrent instability. Not before the surgeon is certain about the biomechanical situation, the surgery can be completed by routine closure of the skin. The standard rehabilitation procedure for the patients involved in this study was described earlier (Methods 2.3.).

Figure G. Under anesthesia, the surgeon manually verifies patellar instability.

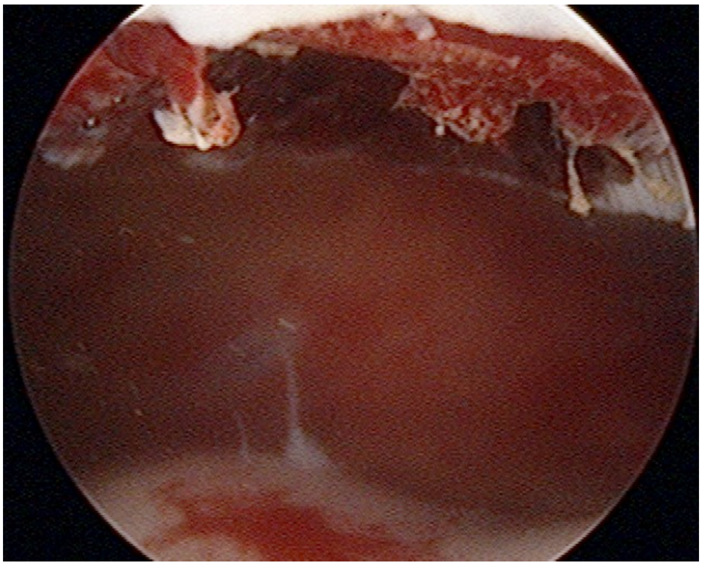
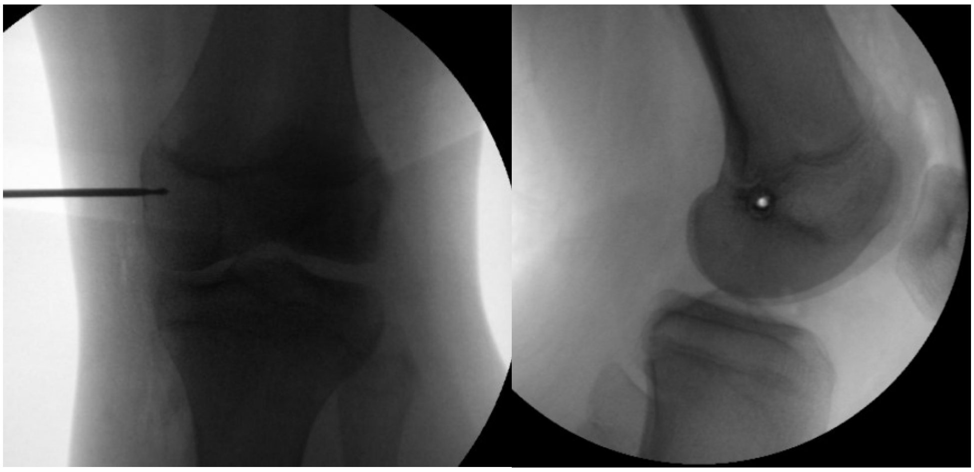


Figure H. Before the open procedure is initiated, arthroscopic exploration gives information about cartilaginous condition, trochlear shape and the site of the torn MPFL.

Figure I. The harvested gracilis tendon is pulled through the second and third layer of the knee capsule by a suture loop.



Figures J and K. Exact drill hole placement is mandatory in order not to damage growth plates.

2.3.2 Kujala's Anterior Knee Pain Score

In 1993, Kujala et al published a scoring system which allowed insights into the subjective symptoms and functional limitations of patients with patellofemoral disorders (168). As anterior knee pain is quite common in patients with PFI, this score is an essential part of the study and gives valid information about the subjective success of MPFL reconstruction. A big advantage of this score is its applicability in all patients. As only daily situations are assessed which do not specifically aim on pain related to sports, individual variation is reduced and therefore the test offers a good objectivity. The test consists of 13 questions with an ideal maximum score of 100. The following figure (L) shows the version published by Kujala et al (168).

1. Limp

(a) None (5)
(b) Slight or periodical (3)
(c) Constant (0)

2. Support

(a) Full support without pain (5)
(b) Painful (3)
(c) Weight bearing impossible (0)

3. Walking

(a) Unlimited (5)
(b) More than 2 km (3)
(c) 1-2 km (2)
(d) Unable (0)

4. Stairs

(a) No difficulty (10)
(b) Slight pain when descending (8)
(c) Pain both when descending and ascending (5)
(d) Unable (0)

5. Squatting

(a) No difficulty (5)

(b) Repeated squatting painful (4)

(c) Painful each time (3)

(d) Possible with partial weight beating (2)

(e) Unable (0)

6. Running

(a) No difficulty (10)

(b) Pain after more than 2 km (8)

(c) Slight pain from start (6)

(d) Severe pain (3)

(e) Unable (0)

7. Jumping

(a) No difficulty (10)

(b) Slight difficulty (7)

(c) Constant pain (2)

(d) Unable (0)

8. Prolonged sitting with the knees flexed

(a) No difficulty (10)

(b) Pain after exercise (8)

(c) Constant pain (6)

(d) Pain forces to extend knees temporarily (4)

(e) Unable (0)

9. Pain

(a) None (10)

(b) Slight and occasional (8)

(c) Interferes with sleep (6)

(d) Occasionally severe (3)

(e) Constant and severe (0)

10. Swelling

(a) None (10)

(b) After severe exertion (8)

(c) After daily activities (6)

(d) Every evening (4)

(e) Constant (0)

11. Abnormal painful kneecap (patellar) movements (subluxations)

(a) None (10)

(b) Occasionally in sports activities (6)

(c) Occasionally in daily activities (4)

(d) At least one documented dislocation (2)

(e) More than two dislocations (0)

12. Atrophy of thigh

(a) None (5)

(b) Slight (3)

(c) Severe (0)

13. Flexion deficiency

(a) None (5)

(b) Slight (3)

(c) Severe (0)

Figure L. Kujala's Anterior Knee Pain Score (168)

2.3.2 Tegner Activity Scale

In 1985, Tegner and Lysholm introduced a scale which focused on the patient's activity level in sports or work rather than on the actual knee function (169). By grading numerically from 0 to 10, the activity level is assessed. Therefore it was used in this study as it apparently gives a good conclusion about the overall postoperative ability to lead an active lifestyle (see Table 2 on the next page).

Level 10	Competitive sports in the National Elite: Soccer, Rugby, Football
Level 9	Competitive sports in lower divisions: Soccer, Rugby, Football, Ice Hockey, Wrestling, Gymnastics, Basketball
Level 8	Competitive sports: racquetball, squash, badminton, track and field athletics, down-hill skiing
Level 7	Competitive sports: tennis, running, motorcars speedway, handball Recreational sports: soccer, football, rugby, bandy, ice hockey, basketball, squash, racquetball, running
Level 6	Recreational sports: tennis, badminton, handball, racquetball, down-hill skiing, jogging 5 times per week
Level 5	Work: heavy labor (construction etc.) Competitive sports: cycling, cross country skiing Recreational sports: jogging on uneven ground at least twice a week
Level 4	Work: moderately heavy labor (truck driving etc.)
Level 3	Work: light labor (nursing etc.)
Level 2	Work: light labor Walking on uneven ground possible, impossible to hike
Level 1	Work: sedentary
Level 0	Sick leave / Disability pension because of knee problems

Table 2. Tegner Activity Scale (169) (170)

2.3.3 2000 IKDC Subjective Knee Evaluation Form

The International Knee Documentation Committee (IKDC), founded in 1987, established several methods for documenting knee surgery and its outcome. The first form was published in 1993 and was called the "IKDC-Standard Knee Evaluation Form". The current version, "2000 IKDC Subjective Knee Evaluation form" was published in 2000. This form assesses the patient's functional outcome and the impairment in sports and daily life and has shown a good validity (171). An adapted version for children was developed. However, the adult version was used in this study. Nevertheless, all forms have been completed under presence of a person in charge for the study and any incomprehension could be cleared immediately.

The ideal maximum value of this score is 100 points and indicates no impairment. The following figure of the 2000 IKDC Knee Evaluation Form was depicted from the website of the American Orthopedic Society for Sports Medicine (172).

2000 IKDC SUBJECTIVE KNEE EVALUATION FORM

Your Full Name____

Today's Date: ______/_______/______ (Day Month Year)   Date of Injury: ______/_______/_____ (Day Month Year)

SYMPTOMS*:

*Grade symptoms at the highest activity level at which you think you could function without significant symptoms, even if you are not actually performing activities at this level.

1. What is the highest level of activity that you can perform without significant knee pain?

   4❑Very strenuous activities like jumping or pivoting as in basketball or soccer
   3❑Strenuous activities like heavy physical work, skiing or tennis
   2❑Moderate activities like moderate physical work, running or jogging
   1❑Light activities like walking, housework or yard work
   0❑Unable to perform any of the above activities due to knee pain

2. During the past 4 weeks, or since your injury, how often have you had pain?

	0	1	2	3	4	5	6	7	8	9	10	
Never	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	Constant

3. If you have pain, how severe is it?

	0	1	2	3	4	5	6	7	8	9	10	
No pain	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	Worst pain imaginable

4. During the past 4 weeks, or since your injury, how stiff or swollen was your knee?

   4❑Not at all
   3❑Mildly
   2❑Moderately
   1❑Very
   0❑Extremely

5. What is the highest level of activity you can perform without significant swelling in your knee?

   4❑Very strenuous activities like jumping or pivoting as in basketball or soccer
   3❑Strenuous activities like heavy physical work, skiing or tennis
   2❑Moderate activities like moderate physical work, running or jogging
   1❑Light activities like walking, housework, or yard work
   0❑Unable to perform any of the above activities due to knee swelling

6. During the past 4 weeks, or since your injury, did your knee lock or catch?

   0❑Yes   1❑No

7. What is the highest level of activity you can perform without significant giving way in your knee?

   4❑Very strenuous activities like jumping or pivoting as in basketball or soccer
   3❑Strenuous activities like heavy physical work, skiing or tennis
   2❑Moderate activities like moderate physical work, running or jogging
   1❑Light activities like walking, housework or yard work
   0❑Unable to perform any of the above activities due to giving way of the knee

Page 2 – 2000 IKDC SUBJECTIVE KNEE EVALUATION FORM

SPORTS ACTIVITIES:

8. What is the highest level of activity you can participate in on a regular basis?

   4❑Very strenuous activities like jumping or pivoting as in basketball or soccer
   3❑Strenuous activities like heavy physical work, skiing or tennis
   2❑Moderate activities like moderate physical work, running or jogging
   1❑Light activities like walking, housework or yard work
   0❑Unable to perform any of the above activities due to knee

9. How does your knee affect your ability to:

		Not difficult at all	Minimally difficult	Moderately Difficult	Extremely difficult	Unable to do
a.	Go up stairs	4❑	3❑	2❑	1❑	0❑
b.	Go down stairs	4❑	3❑	2❑	1❑	0❑
c.	Kneel on the front of your knee	4❑	3❑	2❑	1❑	0❑
d.	Squat	4❑	3❑	2❑	1❑	0❑
e.	Sit with your knee bent	4❑	3❑	2❑	1❑	0❑
f.	Rise from a chair	4❑	3❑	2❑	1❑	0❑
g.	Run straight ahead	4❑	3❑	2❑	1❑	0❑
h.	Jump and land on your involved leg	4❑	3❑	2❑	1❑	0❑
i.	Stop and start quickly	4❑	3❑	2❑	1❑	0❑

FUNCTION:

10. How would you rate the function of your knee on a scale of 0 to 10 with 10 being normal, excellent function and 0 being the inability to perform any of your usual daily activities which may include sports?

FUNCTION PRIOR TO YOUR KNEE INJURY:

	0	1	2	3	4	5	6	7	8	9	10	
Couldn't perform daily activities	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	No limitation in daily activities

CURRENT FUNCTION OF YOUR KNEE:

	0	1	2	3	4	5	6	7	8	9	10	
Can't perform daily activities	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	No limitation in daily activities

The IKDC Subjective Knee Evaluation Form is scored by summing the scores for the individual items and then transforming the score to a scale that ranges from 0 to 100. **Note**: The response to item 10a "Function Prior to Knee Injury" is not included in the overall score. To score the current form of the IKDC, simply add the score for each item (the small number by each item checked) and divide by the maximum possible score which is 87:

$$\text{IKDC Score} = \left[\frac{\text{Sum of Items}}{\text{Maximum Possible Score}}\right] \text{x } 100$$

Figure M. 2000 IKDC Subjective Knee Evaluation Form (172)

2.3.4 Radiographical assessment of trochlear dysplasia and patella alta

All patients presenting with recurrent symptoms of PFI have been evaluated preoperatively by performing axial, a.p. and lateral radiographs. An MRI was additionally performed in order to get relevant anatomical information for surgical planning. As part of this study, additional follow up radiographs were made of those patients who could take part physically. However, all patients included in this study have taken part in planned follow-up examinations and radiography apart from this study and therefore it was possible to assess preoperative and postoperative knee-values of all 26 knees.

By evaluating radiographs and MRI, assessment consisted in comparing preoperative and postoperative patellar heights and furthermore grading the trochlear dysplasia in order to find correlations between dysplasia and outcome. Patellar height was assessed by using the recommended Caton-Deschamps method (see 1.2.5.1), which has been proven to be the most accurate and suitable method for assessing children's knees, being independent from skeletal maturity (65) (69) (75). The Dejour grades A-D for trochlear dysplasia (see 1.2.3) in the participating patients were assessed by a consultant doctor together with a medical student and have been double checked on radiographs as well as MRI, focusing on appearance of the following indicators for dysplasia:

- Flat, convex or even asymmetrical trochlea; cliff pattern
- Crossing sign
- Double – Contour sign
- Supratrochlear spur

2.3.5 Statistical methods

Non parametric tests and descriptive statistical analyses were performed using SPSS. The Kolmogorov-Smirnov test was used to test the data for normal distribution. Because this test showed a non-Gaussian distribution, pre- and postoperative data such as the Kujala Anterior Knee Pain Score and the Tegner Activity Scale were compared with the Wilcoxon-Mann-Whitney-Test. A value of $P = 0.05$ or less was used as the threshold for statistical significance.

3 Results

13 patients were able to take part in the study physically and therefore objective clinical results (apprehension sign, J-Sign) could only be assessed with those patients. However, for the radiological findings it was possible to use pre- and postoperative pictures as well as clinical follow up pictures which have been taken apart from the study. Including 10 patients which could be contacted and surveyed about the subjective scores by telephone it was possible to perform valid statistics of the subjective outcome for in total 23 (13 male and 10 female) patients. The mean age at surgery was 16 years, ranging from 14 to 18 years and the mean age at follow up was 18.9, ranging from 15 to 21. The mean follow up time was 33 months, ranging from 11 to 61 months.

3.1 Radiological and intraoperative findings

All 23 patients (26 knees) presented a more or less severe grade of trochlear dysplasia preoperatively. 11 knees showed the least severe Dejour A grade of trochlear dysplasia. 10 knees showed a grade B dysplasia and 5 knees grade C. None of the knees showed a grade D dysplasia. Only male patients presented dysplasia grade C, while gender-distribution between grade A and B dysplasia is near-equal: 6 females/5 males grade A, 5 females/5 males grade B.

Chondropathia was graded during routine arthroscopy previous to MPFL reconstruction and could be depicted from surgery reports. All knees have been diagnosed with chondropathia in the femoropatellar joint: 11 knees showed grade 1 chondropathia, 8 knees showed grade 2 chondropathia, 6 knees showed grade 3 chondropathia and one knee showed grade 4 chondropathia.

Patellar height was measured before and after surgery (see figure N on the next page). Before MPFL reconstruction, 11 patients showed a Caton-Deschamps index greater than 1.3 (ranging from 1.4 to 2) and have therefore been categorized as patients highly suggestive of patella alta. After surgery, only 6 patients showed a Caton-Deschamps index greater than 1.3. The mean value of patella alta was 1.39 (STD 0.26) preoperatively, while the mean value postoperatively slightly reduced to 1.30 (STD 0.26). However, this result has not been proofed as being statistically significant.

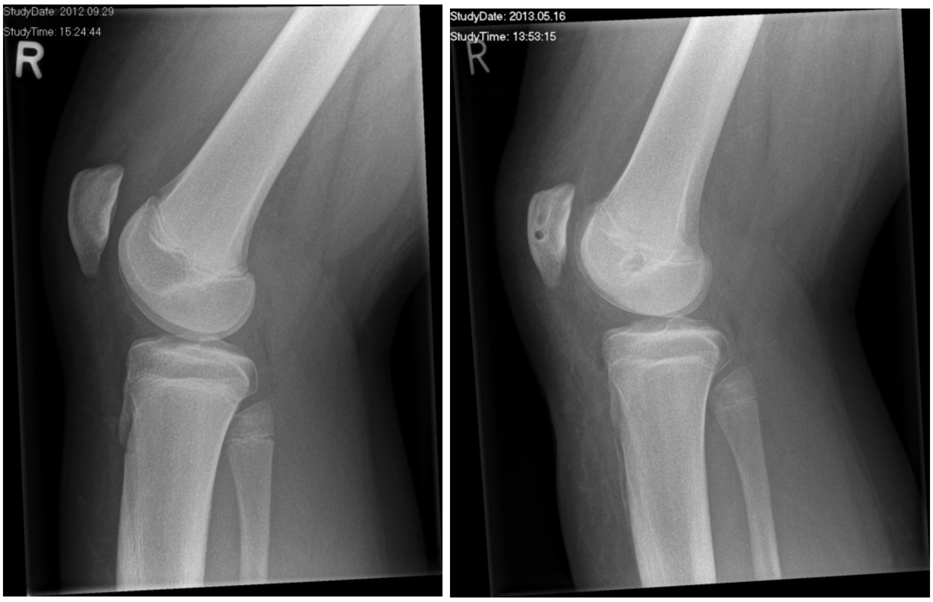


Figure N. The comparison of pre- and postoperative lateral radiographs shows the tendency of the patella to decrease in height after successful MPFL reconstruction. However, the results are not statistically significant.

3.2 Subjective Outcome

The main cornerstone for evaluating the subjective outcome was the comparison between preoperative and postoperative Kujala Anterior Knee Pain Score and Tegner Activity Score. Additionally, the assessment of the 2000 IKDC Subjective Knee Evaluation form and current pain levels assessed by VAS yielded relevant information about postoperative subjective knee function. Furthermore, according to their gained experience, patients were asked if they would let the same surgery be performed once again if they had to decide between surgery and non-invasive therapy anew.

The mean preoperative Kujala Anterior Knee Pain Score (see Figure O on the next page) was 59.58 (STD 23.53) and increased until follow up to 92 (STD 10.48). The same was observed for the Tegner Activity Scale (see Figure P on the next page): mean preoperative values were 3.19 (STD 1.89) and increased postoperatively to 5.35 (STD 1.74). Interestingly, preoperative mean values of both Kujala and Tegner did not differ widely between male and female patients (Kujala: 57.67 for males, 62.18 for females, Tegner:

3.47 for males, 2.82 for females). In contrast, postoperative values showed significant differences in gender: mean Kujala values were 97.33 in males and 84.73 in females and mean Tegner values were 5.93 in males and 4.55 in females. All those statistics were statistically significant with p-values < 0.05. No significant correlation could be found between higher grades of trochlear dysplasia and poorer subjective score outcomes.

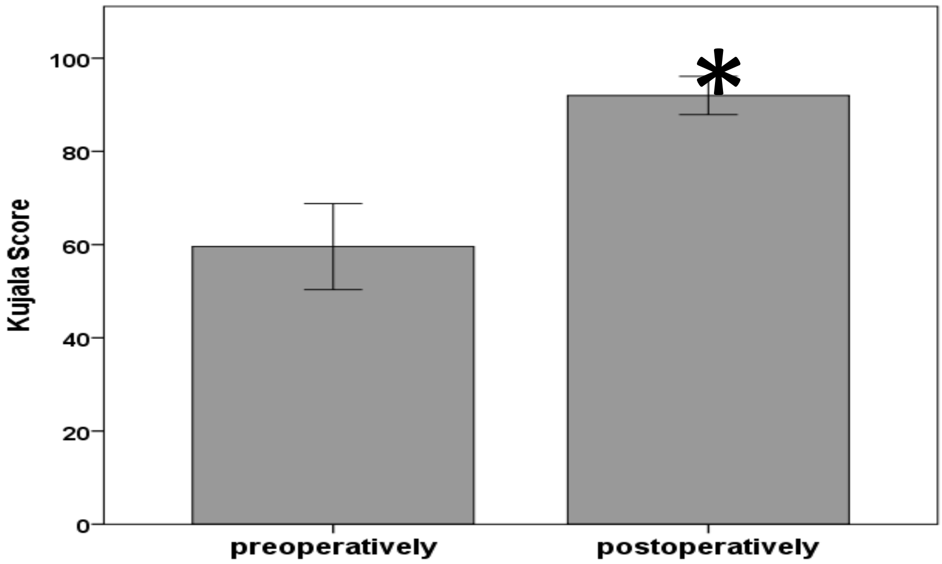


*Figure O. The Kujala Score. Values increased from a mean of 59.58 preoperatively to 92 postoperatively. *p < 0.05*

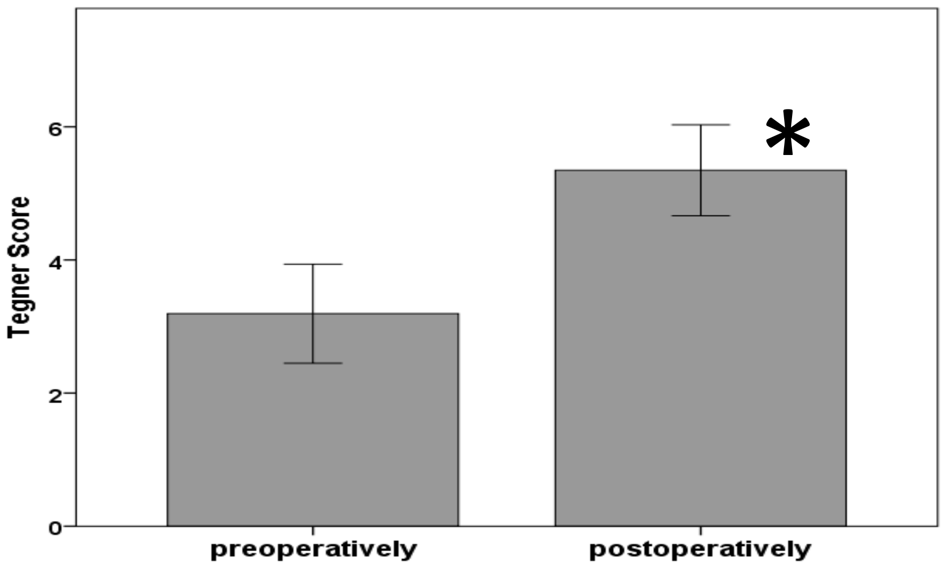


*Figure P. The Tegner Activity Scale. Values increased from a mean of 3.19 preoperatively to 5.35 postoperatively. *p < 0.05*

The mean follow up value of the 2000 IKDC Subjective Knee Evaluation form was 97 (STD 12.8). However, two patients with a low value of 62 and 69 gave controversial replies to the other tests, such as a quite high level of 7 and 9 in the Tegner Activity Score.
The mean postoperative VAS was 1.1. The values did not show significant differences in gender.
Generally, there was a high grade of satisfaction. 20 patients would choose to re-perform the same surgery if they happened to be in the same situation again. Apparently, the desired effect of long lasting stability could be established from their point of view. Nevertheless, three patients thought that the surgery did not achieve the expected results and would not accept MPFL reconstruction again. Of those three patients, two could give explanatory statements. For the first patient, a change of lifestyle would probably have brought similar effects, PFI only occurred during soccer. In those times, the patient was in a professional soccer team and had plans to quit anyway. The second patient thought that being more cautious would have sufficed.

3.3 Objective Outcome

The objective outcome consists of the previously described radiological findings of 23 patients (see 3.1 Radiological and intraoperative findings) and on the clinical examination of the 13 patients who took part in the study physically.
The clinical evaluation showed following results: No patient showed limping and all could walk on tiptoe as well as on the heel. All patients were asked to squat deeply. 12 patients squatted, one refused; four of the patients experienced pain during squatting. During squatting, patellar tracking was observed: no patella showed maltracking. This goes hand in hand with generally satisfying postoperative tangential radiographs of the patella (see Figures Q and R on the next page). Two of thirteen patients had a positive J-Sign and a positive apprehension sign in full extension. The apprehension sign disappeared in both patients in 30° flexion.
Four patients complained of pain during squatting. Two of the patients complaining of pain (VAS = 5 and 6) during squatting and peripatellar tenderness had a positive Clarke Sign and a grade 3 chondropathia. The other 9 patients were free of pain. Besides, crucial ligaments were tested with the Lachmann method and the drawer test apart from the patellofemoral assessment and showed no signs of laxity or rupture.

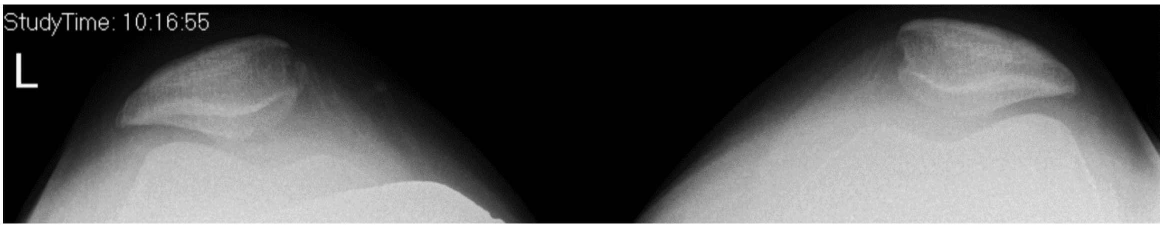


*Figure Q**

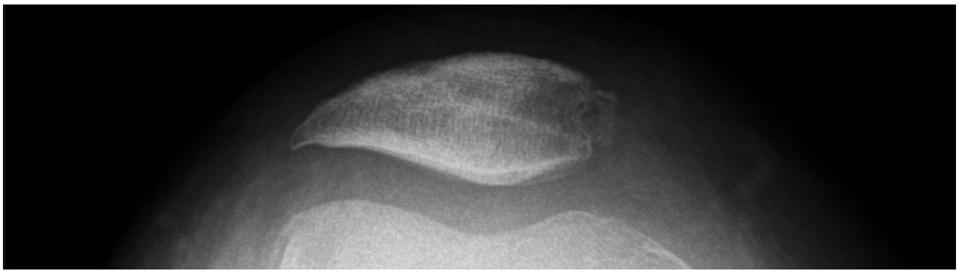


*Figure R**

**Figures Q and R: The tangential views of the patella preoperatively (Figure Q) and postoperatively (Figure R) demonstrate the effect of MPFL reconstruction regarding patellar tracking.*

3.4 Failure and complications

Failure of treatment was regarded as recurrent instability marked by tendency to subluxation, the feeling of insecurity or even further dislocation. Also, high pain levels at follow up were regarded as partial failure of treatment. Apparently, patients with the highest grade of chondropathia also showed the highest VAS. Common complications like infection, bleeding or thrombosis have been assessed additionally.

Two patients experienced recurrent subluxation and one patient had a traumatic redislocation. The patient with recurrent dislocation had a grade 2 chondropathia and a Dejour grade B dysplasia on both knees. The other two patients with recurrent PFI had a grade 2 chondropathia/Dejour grade C dysplasia respectively grade 1 chondropathia/Dejour Grade A dysplasia. The patient with recurrent dislocation had an increase in the Kujala Anterior Knee Pain Score from 56 to 86 and the Tegner-Activity Score increased from 3 to 4. The two patients with recurrent PFI showed divergent results in Kujala and Tegner Scores: while one patient increased from 55 to 94 for Kujala and 3 to 5 for Tegner, the other patient decreased from 92 to 70 for Kujala and 4 to 1 for Tegner. Two patients have been revised. One presented a too tight MPFL reconstruction, in this case a Z-lengthening was performed. The other patient was treated with reefing of the gracilis autograft, tuberositas medialization and lengthening of the lateral retinaculum due to laxity of the MPFL reconstruction.

Interestingly, two of the three patients regarded as failed treatment (1 patient with recurrent PFI and 1 patient with recurrent redislocation) would still choose this surgical procedure anew. One patient experienced slight infection of the surgical site in the postoperative phase and was successfully treated with antibiotics.

4 Discussion

Several procedures for correction of recurrent PFI have been described in literature. While some methods have been proven to be unsuitable and might even provoke adverse effects, others could be more or less established over the years (34) (40) (173). Surgical therapy of patellar dislocation and PFI has received wide attention since the importance of the MPFL for a stable patella has been demonstrated. Due to the fact that the MPFL significantly contributes to patellar stability and prevents lateral dislocation, reconstruction of it seems to be an expedient and adequate therapy (42) (167) (174). Although MPFL reconstruction is regarded as an efficient method, variable results have been reported and there is no common conclusion about the ideal technique. For pediatric patients, soft tissue procedures have been questioned as being insufficient. Studies report of higher recurrence and revision rates of up to 21 % after MPFL reconstruction compared to rates of 3% in adult patients (163). Additionally, treatment in pediatric patients is limited due to skeletal immaturity.

Therefore, the main purpose of this study was to contribute data of pediatric patients who underwent MPFL reconstruction with the proposed method by Schoettle et al (2009) due to recurrent PFI or primary dislocation (167). Since the long term outcome after MPFL reconstruction is one of the most debated issues, this study gives complementary information. According to a study by Palmu et al (2009), the highest redislocation rates have been found within 2 years after surgery. Therefore, mean follow up time of 33 months can be regarded as a sufficient long term outcome (138). Common outcome parameters like recurrence, pain, function and satisfaction have been questioned. Besides, patellar height was measured preoperatively and postoperatively in order to quantify a study by Fabricant et al (2014), which demonstrated improvements in patients with patella alta after MPFL reconstruction (175). This study could not contribute sufficient data in order to support Fabricant's findings, although a slight decrease of patellar height could be found. Therefore, this pleasant side-effect of MPFL reconstruction cannot be declined (175).

Improvements in all subjective assessment scores have been demonstrated. However, male patients seem to benefit more from reconstruction and reach higher grades of postoperative activity than females; the reason for that could not be found. Nevertheless, the mean outcomes are compatible with a sporty lifestyle and restrictions only have to be made in competitive sports or intense individual sport, especially including sports with a high grade of knee joint strain. 87% of all patients would choose this treatment method again. Concluding from the statements given by the patients unwilling to re-perform this surgery, indication for surgery should be adjusted to the individual patient's level of activity. If a patient with recurrent dislocation while sporting is willing to reduce those activities known for causing patellar dislocation, a non-surgical therapy could be evaluated.

Anatomic reconstruction with both ideal insertion and length of the autograft should be the principle, as excessive contact pressures might cause pain (176). The correlation between degree of trochlear dysplasia and worse subjective outcome could not be established; however, the number of patients participating was too low to discover any significance. The hypothesis, that high grade chondropathia causes higher pain levels can be confirmed in this study.

4.1 Restrictions

The mean age of the patients at the time of surgery was 16 years. Although still pediatric, the skeletal maturity is different to younger patients and therefore further studies with younger patients will be needed in order to quantify the results of the present study. Furthermore, the chosen treatment in 8 knees was a combination of MPFL reconstruction and tibial tubercle transfer while statistics considered the outcome of all patients in general.

4.2 Conclusion

Reconstruction of the MPFL and also combined treatment with tibial tubercle transfer is a valuable method for treating recurrent patellar instability effectively in adult patients as well as pediatric patients. Persistent instability and pain are the potential complications. The limiting factor is severe trochlea dysplasia which cannot be addressed by soft tissue technics exclusively. Femoropatellar chondropathia, caused by recurrent dislocation, can be avoided with early treatment and patellar stabilization. MPFL reconstruction is a promising method and shows remarkable results despite its relatively recent introduction in orthopedic surgery.

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