Tibial and Trochlear Osteotomies

A Safe Track Towards Patellar Stability

Jordy D.P. van Sambeeck

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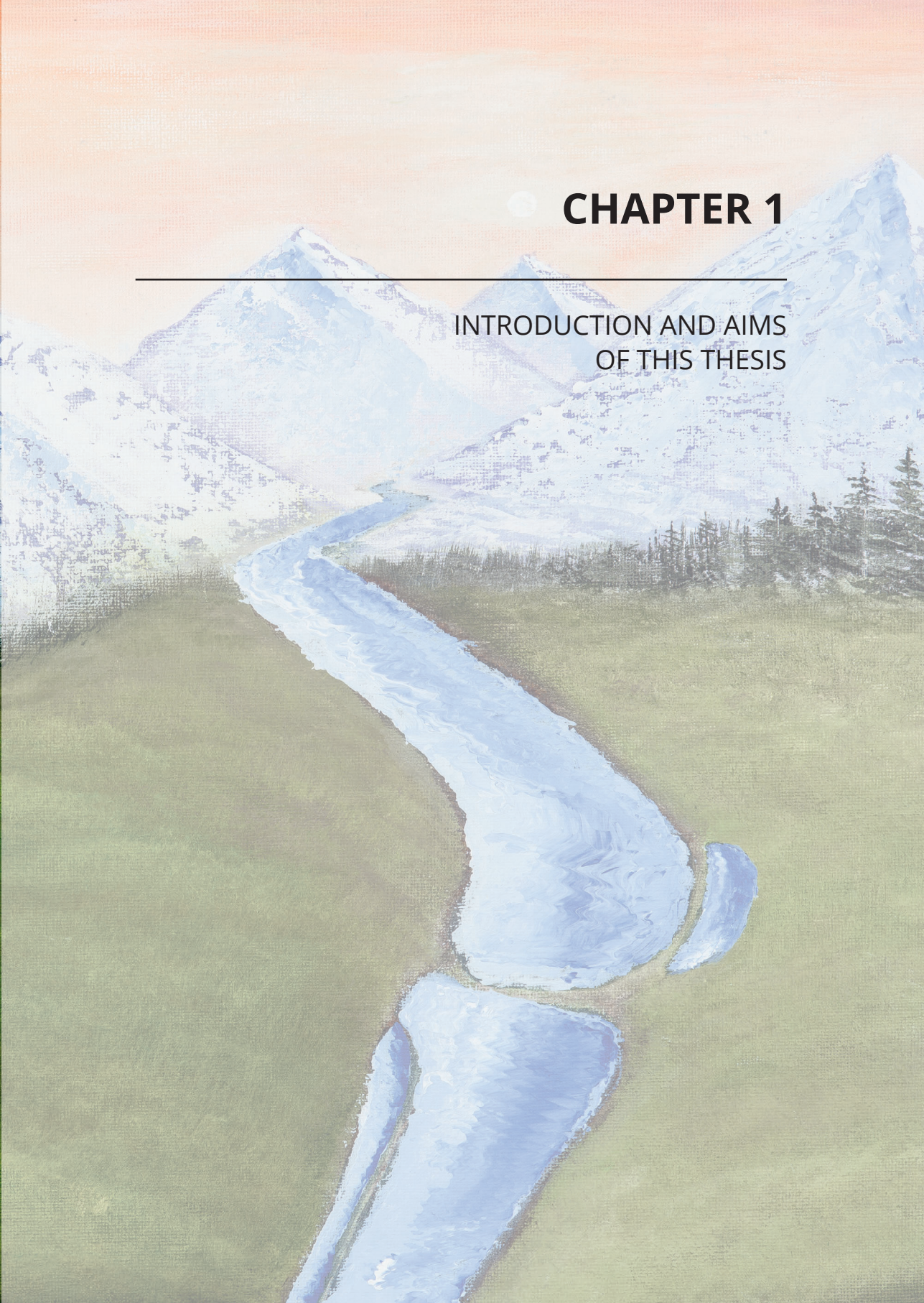

CHAPTER 1

INTRODUCTION AND AIMS OF THIS THESIS

Background and physiology of the patellofemoral joint

The scope of this thesis is on patellofemoral instability and includes diagnostics, osteotomies and outcome of treatment of patellofemoral instability. The aim is to optimize the treatment of patients with patellofemoral instability by increasing knowledge on certain aspects of treatment, on the continuous track to the best possible care.

The patella (kneecap) is the largest sesamoid bone of the human skeleton. The patella articulates with the trochlea of the femur and increases the lever arm of the extensor mechanism, thereby increasing the extension moment of the quadriceps muscle. The articulation between the patella and the femoral trochlea is called the patellofemoral joint. The patellofemoral joint is aligned by bony structures and is surrounded by soft tissue structures such as the quadriceps tendon, patellar tendon, medial patellofemoral ligament (MPFL), lateral patellofemoral ligament and the retinaculum of the knee (figure 1 and figure 2).

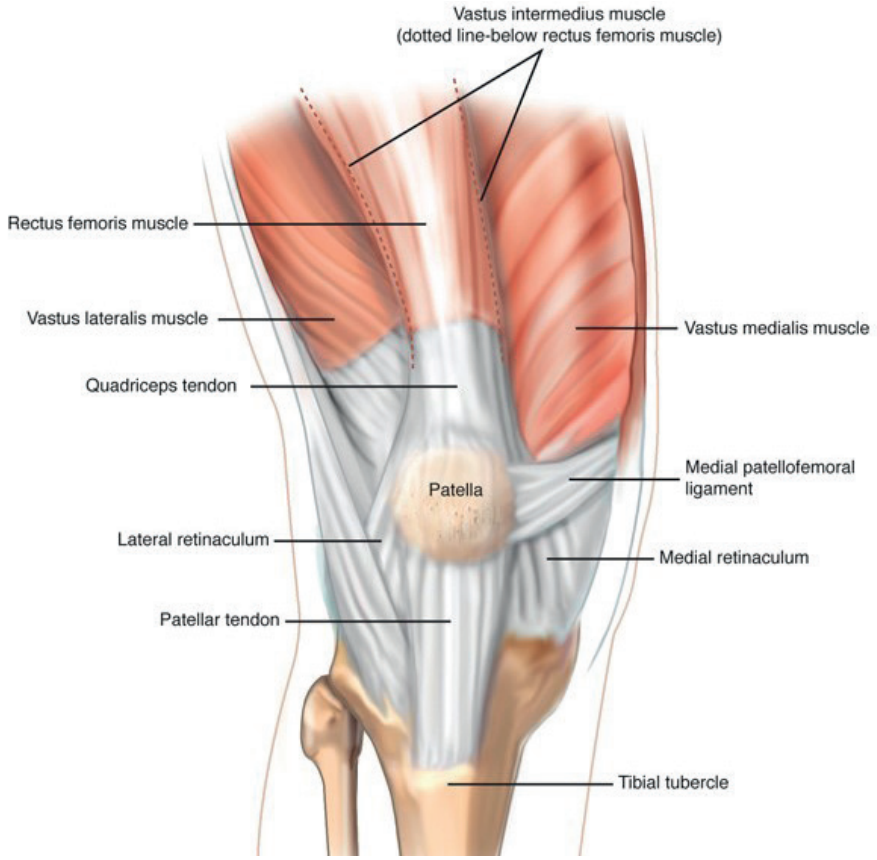

Figure 1. The patella surrounded by its soft tissue structures.

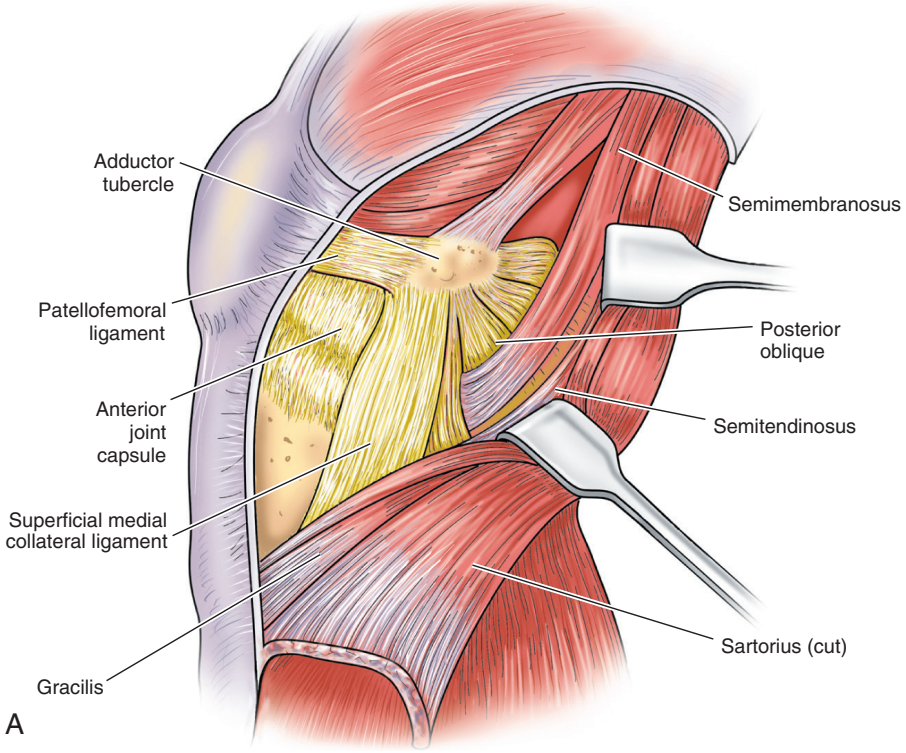

Figure 2. Medial aspect of the knee including the medial patellofemoral ligament. This figure was published in Insall & Scott Surgery of the Knee, Sixth Edition, 2018, Chapter 1 Anatomy, Figure 1.64, Page 32, Copyright Elsevier (2018).

In a normal knee, the patella is stable during full range of motion of the knee, including flexion and full extension. This patellofemoral stability is maintained by static stabilization on one hand and by dynamic stabilization on the other hand. Static stability is provided by bony and soft tissue structures and includes indirect stabilization by alignment of the leg and direct stabilization by anatomy of the patella and the trochlear groove. Dynamic stability is provided by the action of muscles. Failure to stabilize the patella can lead to lateral patellar dislocation.

In full extension of the knee, the normal position of the patella is lateral from the trochlear axis and the patella is disengaged from the trochlea. Then, in early knee flexion (6-20°), the patella translates medially, reflecting the initial contact against the proximal part of the lateral rim of the trochlea which is a bony restraint to lateralization [1]. The MPFL is the primary static restraint to lateral patellar translation in early knee flexion up to 30°, contributing to 60% of the restraining force of the soft tissue structures [2]. The midpoint of the patellar median ridge crosses the proximal limit of the trochlear groove at around 22° of flexion[1], indicating that more than half of the articular surface of the patella is in contact with the

trochlea. When this amount of engagement of the patella in the trochlear groove is reached, this is a biomechanically very stable situation due to static stabilization of a congruent patellofemoral joint.
Next to this static stabilization, dynamic stabilization is important in maintaining patellofemoral stability when moving the knee. Dynamic stabilization occurs by the activation and relaxation of co-acting muscles and muscle groups that directly or indirectly influence the position of the patella relative to the trochlea. The quadriceps muscle (including the vastus medialis obliquus) and both the hip external rotators and hip abductors are important dynamic stabilizing muscle groups. Activation of the external rotators of the hip, especially the gluteus maximus muscle, may reduce laterally oriented force vector on the patella. By activating these muscles, the femur (including the knee) is externally rotated and the force vector on the patella is directed less laterally due to a change in the functional mechanical alignment. Activation of the vastus medialis obliquus (VMO) resists lateral patellar displacement by carrying out a posterior and medially directed force[3]. Relaxation of the VMO reduces the force required to displace the patella laterally[3].

Pathophysiology of patellofemoral instability

Patellofemoral joint disorders can be caused by abnormal bony alignment and abnormal function of surrounding soft-tissue structures and muscles. Patellofemoral joint disorders can roughly be classified as patellofemoral instability and patellofemoral pain. This thesis focuses on patellofemoral instability. Patellofemoral instability includes complaints of giving way, lateral tracking of the patella, lateral subluxation and lateral dislocation of the patella. A primary patellar dislocation often occurs during pivoting activities including sports such as soccer and handball, but can also occur during activities of daily life. The patella usually dislocates in early flexion (0-30 degrees of flexion), often when the knee moves from full extension into early flexion, for example when landing after a jump. It is often a non-contact injury. After a patellar dislocation the medial capsule of the patellofemoral joint is elongated or ruptured, including the MPFL.

Patellofemoral instability is a multifactorial problem. Multiple risk factors for primary patellar dislocation and recurrent patellar dislocation have been described in literature and include anatomic and demographic risk factors[4, 5] and lack of dynamic stabilization. Anatomic risk factors for primary and recurrent patellar instability that are in general accepted as evident risk factor are trochlear dysplasia, patella alta and a lateral position of the tibial tubercle in the coronal plane. These risk factors will be outlined below. Contributing anatomic factors are femoral anteversion, tibial exotorsion, knee hyperextension and a valgus knee axis. All of these risk factors directly or indirectly affect bony stabilization of the patella by affecting alignment or local anatomy leading to an increased laterally directed force on the patella or a decreased restraint to lateral translation. These

anatomic risk factors are generally accounted for in the standard workup, but the amount of contribution of a risk factor to patellofemoral instability is still a matter of debate. There is not a simple relationship between one anatomic risk factor and patellar instability.

A normal trochlea has a sufficient depth, length, sulcus angle and lateral trochlear inclination angle to contain the patella during the whole range of motion. The sulcus angle and lateral trochlear inclination angle represent measurements of the depth of the trochlear groove relative to the medial and lateral facet. A decreased angle, means an increased depth of the groove. In trochlear dysplasia the development of the trochlea has resulted in an abnormal geometry, with a too shallow, a flat or even a convex shape of the sulcus[4]. This results in insufficient bony restraint to lateralization of the patella and/or to a bump that the patella needs to override to enter the shallow groove and with that to a higher risk of patellar instability and dislocation.

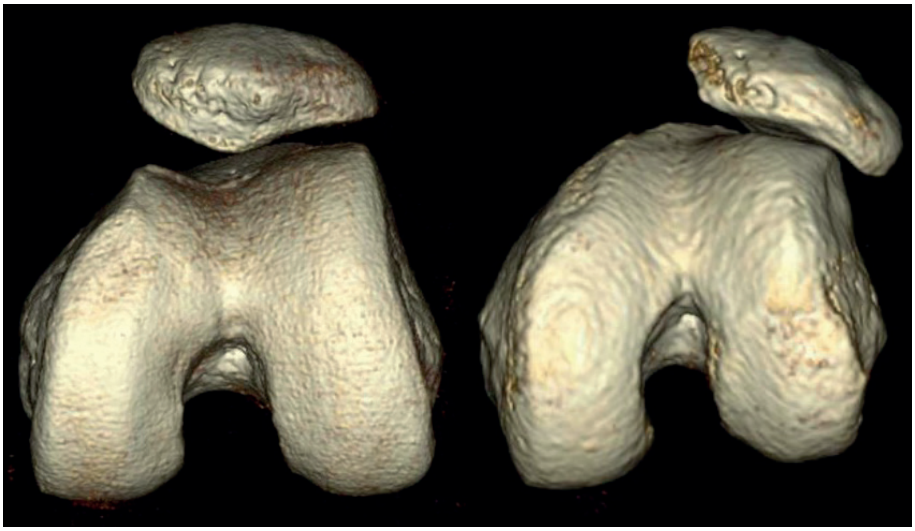

Figure 3. On the left the bony alignment of the patella and trochlea in a normal knee. On the right in a knee with trochlear dysplasia. The left part of each knee is the medial side.

Patella alta ('alta' is the Latin word for high) means that there is a too high position of the patella relative to the trochlea. Patella alta results in a later engagement of the patella into the trochlear groove when flexing the knee from the neutral position. This means that there is a longer trajectory of the patella without engagement in the trochlea leading to later restraint to lateral translation by the trochlea. This can contribute to instability and/or dislocation of the patella in early flexion.

Lateralization of the tibial tubercle relative to the trochlear groove (or any other reference point that could be used) results in an increased lateral directed force

on the patella[6]. The mediolateral position (i.e. the position in the coronal plane) of the midpoint of the tibial tubercle relative to the midpoint of the insertion of the patellar tendon at the inferior pole of the patella defines the line of action of the patellar tendon on the patella. The angle between the line of action of the patellar tendon and the direction of the resultant force of the quadriceps is a representation of the direction of force on the patella when contracting the quadriceps muscle (figure 4). The resultant of the forces acting on the patella in the coronal plane includes a lateral component when the quadriceps is activated, which increases with increased lateralization of the tibial tubercle. A lateral directed force may be generated when the quadriceps eccentrically activates in early flexion; this may subsequently contribute to patellar instability and even provoke a patellar dislocation.

As mentioned before, after a primary patellar dislocation, the MPFL is elongated and most often ruptured[7]. Being the most important static soft tissue restraining force against lateral translation, it is an important structure contributing to patellofemoral stability. Therefore, injury of the MPFL after a primary patellar dislocation should always be taken into account as risk factor for recurrent instability.

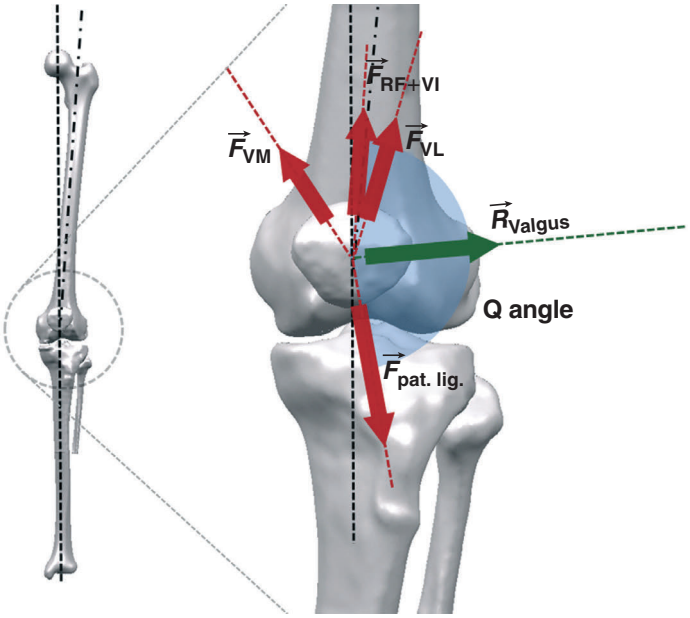

Figure 4. Q-angle. The Q-angle is the angle between the quadriceps' line of pull and the patellar tendon. The quadriceps' line of pull is determined by direction of force of the vastus medialis, vastus intermedius, vastus lateralis and rectus femoris. The direction of the patellar tendon partially depends on rotation of the tibia. While extending the knee, the tibia rotates externally, thereby further increasing lateralization of the tubercle and the Q-angle. This figure was published in Insall & Scott Surgery of the Knee, Sixth Edition, 2018, Chapter 18 In Vivo Kinematics of the Patellofemoral Joint, Figure 18.2, Page 314, Copyright Elsevier (2018).

Clinical presentation and physical examination

Patients can present with patellofemoral instability, patellofemoral pain (often referred to as anterior knee pain) or a combination of those symptoms. It can be difficult for patients to distinguish instability from pain and consequently it can be a challenge for physicians to differentiate between those problems.

Patients with patellofemoral pain often describe a continuous pain that increases with certain activities. Patients with patellofemoral instability may experience a feeling of giving way of the knee as a consequence of reflective muscle relaxation due to unexpected pain or contrary a feeling of a locked knee due to a reflective muscle activation.

Patellar dislocation is not always recognized by the patient or bystanders and can be mistaken for a subluxation because typically (in 90% of cases) the patella relocates spontaneously. After a primary patellar dislocation patients often present with pain and the inability to bear weight on the affected knee. There is often swelling due to hemarthrosis and a limited range of motion (no full extension, maximum of 60-70° flexion) on physical examination. Provocative tests are not very informative at the acute moment, but particularly unpleasant for a patient in this setting.

Patients who present on outpatient clinic without a recent acute event can be examined more extensively. Inspection can provide the physician with information on patellar height with knees in 90 degrees of flexion and on lateralization and tilt of the patella with the knee in extension. The physician should asses the bony anatomy including the leg axis and femoral and tibial rotational deformities. The Q angle can be measured in laying or standing position. A patient can be asked to perform a single leg squat to assess the neuromuscular control. Active range of motion should also be tested in open chain to examine patellar tracking. During range of motion examination of the knee, the physician should look for the J-sign. The J-sign is seen when the patella shifts abruptly laterally when exiting the trochlear groove as extension progresses and is a typical finding which indicates initial excessive lateral tracking of the patella. Patellar stability can be tested by passive movement of the patella mediolaterally in a fully extended knee and by the apprehension test (figure 5). Patients should be examined for general hyperlaxity, for example by determining the Beighton score[8].

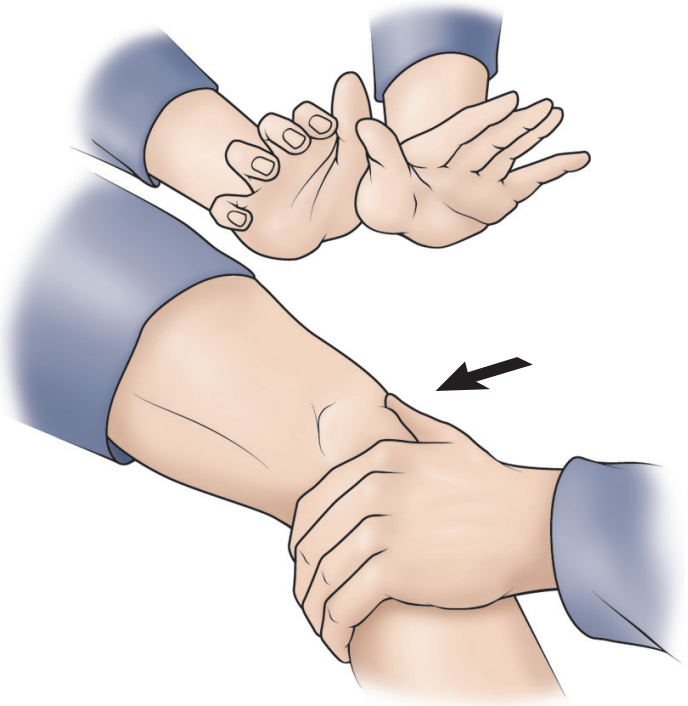

Figure 5. Apprehension test (Insall Scott, Ch 65, Disorders of the PF joint)

The patient lies supine with completely relaxed legs. The examiner pushes the patella gently laterally. The test is positive when the quadriceps muscle is activated involuntary or by reflex and this represents chronic patellar instability. This figure was published in Insall & Scott Surgery of the Knee, Sixth Edition, 2018, Chapter 65 Disorders of the Patellofemoral Joint, Figure 65.9, Page 848, Copyright Elsevier (2018).

Imaging

Radiographic imaging has an important role in the decision making for treatment of patients with patellofemoral instability. The radiographic imaging modalities that are used include conventional radiography (CR), computational tomography (CT) and magnetic resonance imaging (MRI).

Conventional radiographs can provide the clinician with information on the current position of the patella, (osteochondral) fractures, patellar height and trochlear morphology[4]. Often additional imaging is required for an adequate assessment of injury and anatomy of the patellofemoral joint and surrounding structures. MRI scanning provides additional information on possible injuries such as (osteo)chondral injury, chondral damage and tear of the MPFL[7]. Anatomic risk factors such as trochlear morphology, lateralization of the tibial tubercle and

patellar height can also be determined on MRI. CT scanning provides information on anatomic risk factors such as bony anatomy of the trochlea, lateralization of the tibial tubercle and patellar height but does not provide information on the cartilaginous and tendinous structures.

There are some specific issues that should be considered when interpreting measurements of radiographic imaging of the patellofemoral joint. These include patient position, leg position, load of the leg, difference in measurement for different imaging methods and variability of measurements. For example, it should be taken into account that MRI and CT are performed with the patient supine without any load on the leg, this gives different results than CR concerning patellar height. Importance of leg position was previously illustrated by false outcomes of trochlear anatomy on CR with minimal rotation aberrations of 5°[9]. Different leg position between CT- and MRI-scans could result in different outcomes of patellar height measurements[10]. A CT-scan is made with the knee in full extension, an MRI is typically made with the knee in 20° flexion.

Hochreiter et al. demonstrated high variability in values of measurements that describe the anatomy of the 'normal' trochlea such as sulcus angle, trochlear depth and lateral femoral trochlear inclination[11]. This might be a result of the complex three dimensional anatomy of the trochlea which include differences in the transverse, coronal and sagittal plane, as well as of differences due to heterogeneity in methodology.

Trochlear anatomy was originally assessed on conventional radiographs conform the description of Dejour, whose classification is still used in practice[4] (figure 6 and 7). Despite that the Dejour classification is a simplification of the three dimensional anatomy of the trochlea, it is useful to discriminate between mild (type A) and high grade (type B-D) trochlear dysplasia. Therefore, it can be helpful to direct the type of surgical treatment. The increased availability of CT and MR imaging after the initial description of Dejour has led to more possible and often more reproducible measurements of the trochlear anatomy. New additional assessment methods to classify trochlear morphology might lead to new classification methods and treatment strategies.

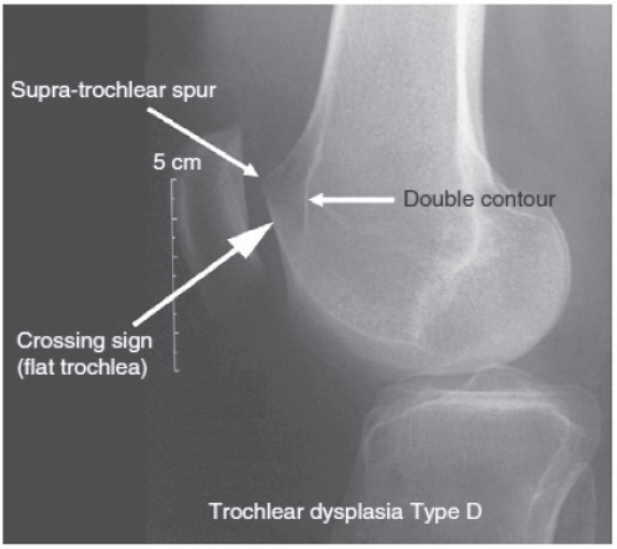

Figure 6. The three findings identifying trochlear dysplasia on lateral X-ray views: crossing sign, double-contour sign, and supratrochlear spur. Saggin PRF, Saggin JI, Dejour D; Imaging in Patellofemoral Instability: An Abnormality-based Approach. *Sports Med Arthrosc Rev* 2012;20:145-151.

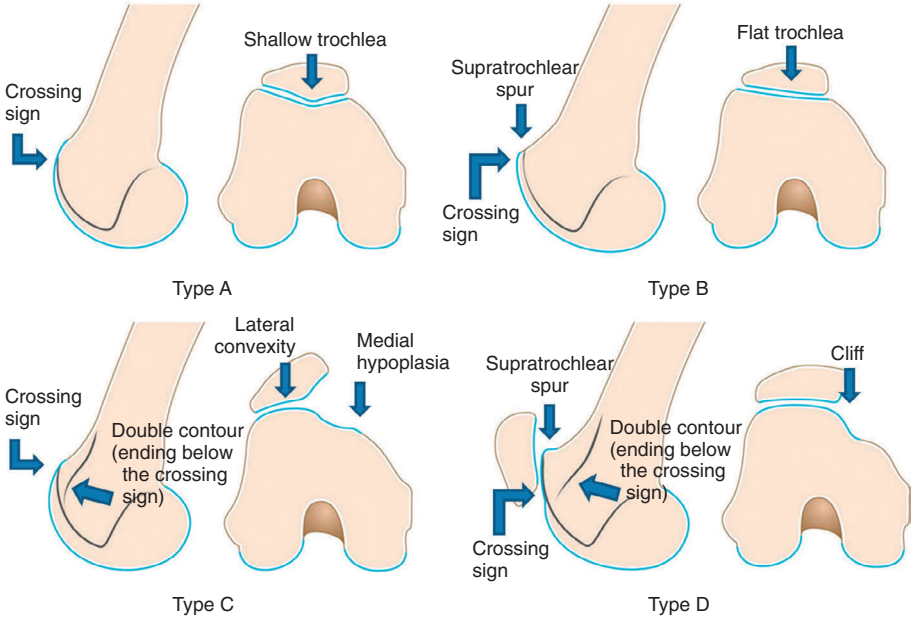

Figure 7. Trochlear dysplasia classification according to D. Dejour. This figure was published in Insall & Scott Surgery of the Knee, Sixth Edition, 2018, Chapter 65 Disorders of the Patellofemoral Joint, Figure 65.14, Page 851, Copyright Elsevier (2018). (Insall Scott Ch. 65, Imaging)

Patellar height measurement was originally described on CR. Multiple measurement methods are described, several of them are widely used including the Insall-Salvati ratio (IS)[12], Caton-Deschamps ratio[13], modified Insall-Salvati ratio (MIS)[14] and Blackburne-Peel ratio (BP)[15], these will be explained by an illustration in chapter 2. Most of the measurement methods can also be performed on CT or MR images, in which case different normal values might be used[16]. The patellotrochlear index (PTI) is a measurement method that is specifically designed for measurement on MRI images[17].

Lateralization of the tibial tubercle can be measured on CT and MR images. The original measurement method measures the mediolateral distance in millimeters between tibial tuberosity and trochlear groove on axial slices of CT and is called the tibial tubercle-trochlear groove distance (TT-TG)[4]. This measurement can also be performed on MRI images, for which different normal values should be used. Measurement of the TT-TG is still the most often used measurement method of lateralization of the tibial tubercle, despite its known difficulties in patients with trochlear dysplasia[18]. There are alternative measurement methods such as the tibial tubercle – posterior cruciate ligament distance (TT-PCL) and the recently described tibial tubercle – mid inter-epicondylar line trochlea intersection (TT-MIELTI)[19]. However, it is not well known if there is a clinical relevant advantage of these two different measurement methods, further investigation on this is needed.

Combining CR, CT and MRI as imaging methods with the possible multiple measurements methods of anatomic risk factors could result in an overload of information, without being able to create a uniform treatment plan which is consistent with all measurements. It is advisable to develop a standard diagnostic imaging workup with a selected amount of measurements on CR and CT or MRI which complement each other. Difficulties that exist in choosing the combination of best imaging modality with the best measurement method include differences in normal values on different imaging modalities, differences in normal values during growth, differences between 2-dimensional and 3-dimensional imaging, differences in the display of bony and soft tissue structures and ease of the measurement method. This is only a limited enumeration of issues without further explanation or discussion that can influence outcome of the measurements.

Treatment

Tibial tubercle osteotomy and trochleoplasty

Treatment of patients with patellofemoral instability is challenging due to the many interacting factors that can contribute to the pathology of an individual patient. In a recent thesis on treatment of patellofemoral instability, Rood et al. formulated an algorithm for treatment of objective lateral patellar dislocation based on clinical experience and studies in the thesis which may help to identify the specific treatment for an individual patient with certain pathology.

Treatment after a first time lateral patellar dislocation starts non-operatively. The optimal non-operative treatment is functional treatment with minimal immobilization of the knee and stimulating early active rehabilitation[20].

For patients with recurrent patellar instability despite adequate non-operative therapy, surgical treatment can be considered. Different procedures may be combined, the corner stone of optimal patella stabilizing surgery is reconstruction of the medial patellofemoral ligament. This can be combined with a procedure which addresses the bony anatomy such as a medializing and/or distalizing tibial tubercle osteotomy (TTO) and a trochleoplasty. In some cases even distal femoral osteotomy could be added correcting for rotation or malalignment in the coronal plane. In this thesis the trochlear osteotomy and tibial tubercle osteotomy will be addressed.

A more general term for trochlear osteotomies or procedures which modify the trochlea is 'trochleoplasty'. Trochleoplasty procedures are technically challenging procedures. Different techniques have been described historically[21]. The different techniques could be categorized in trochlear deepening and lateral facet elevating or elongating techniques (figure 8). The general aim of a trochleoplasty is to reshape the trochlear groove in a way that the patella engages into the trochlear groove in early flexion and is then restrained from lateralization during the whole arc of motion of the patella when flexing and extending the knee. Trochleoplasties are intra-articular osteotomy procedures and have inherently a risk of damaging the patellofemoral joint during the procedure. Despite a careful surgical technique, possible complications could include osteochondral damage, osteochondral fracture, osteochondral necrosis or ligamentous damage. Extensive intra-articular procedures such as a trochleoplasty could also have an increased risk on arthrofibrosis (causing stiffness) of the knee. Besides the direct and short term complications, modification of the trochlea could also have long term effects. The congruency of the patellofemoral joint is modified only at the trochlear side and not on the patellar side. There may be a relationship between patella and trochlea morphologic development during growht[22]. So, modifying only the trochlea results in some kind of increased incongruency of the joint. This could, amongst other factors or complications, possibly lead to early patellofemoral osteoarthritis.

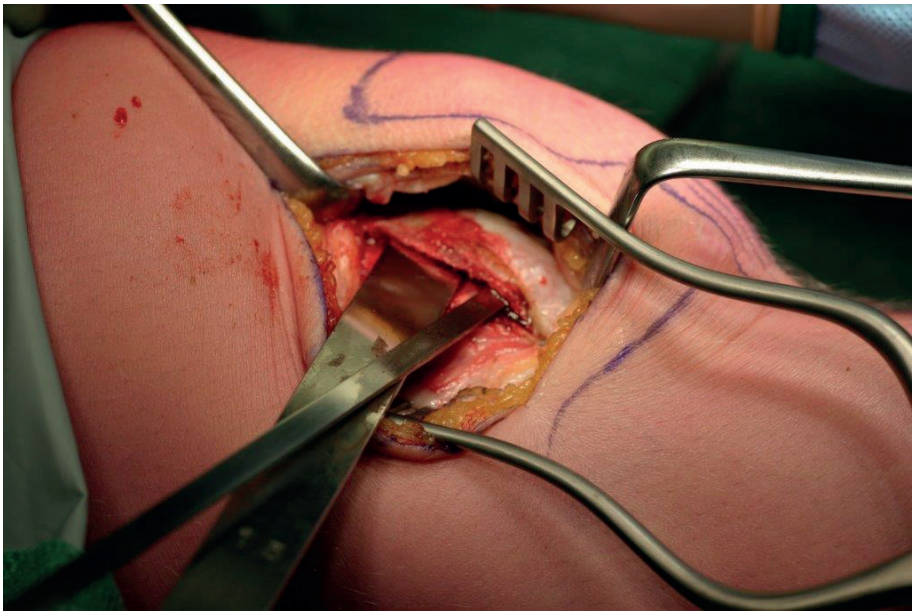

Figure 8. Lateral facet elevating trochlear osteotomy. The osteotomy is performed with osteotomes, the proximal is further advanced medially than the distal osteotome. A triangular bone graft or tricalcium phosphate wedge is used to hold the achieved correction.

Historically there have been multiple procedures addressing lateralization of the patellar tendon insertion. A bony procedure is preferred due to the better healing potential of bone compared with tendons and more accurate measurable correction, bony procedures are consequently the most often described option in recent literature. Some bone-specific complications of surgical intervention include fracture and non-union. Different surgical techniques may lead to a different amount of these bone-specific complications. Factors that could contribute are disruption of blood supply to the bony fragment or technique of fixation. The occurrence of major procedure specific complications after a TTO might be related to the technique that is performed[23]. Nonunion and fracture are two complications that could be related to surgical technique and postoperative care. Bone healing can occur as primary or as secondary bone healing, these are different methods of healing, which require different methods of immobilization. For the TTO primary bone healing is the desired method of bone healing, requiring absolute stability and compression over the 'osteotomy'. This is accomplished by using lag screws as fixation. Next to the method of stabilization, there needs to be enough blood supply to the osteotomy supplying nutrients and oxygen which are essential for healing. Blood supply to the bone can be either periosteal or endosteal. Surgical dissection interferes with the blood supply of the bone. Different techniques can differently affect these ways of blood supply and could therefore theoretically lead to different rates of (non)union. Next to the effect on blood supply, different

techniques of osteotomy can differently affect biomechanical properties of the tibia. Various osteotomy techniques lead to different stress risers thereby affecting the fracture probability. So, different techniques can differently alter the blood supply of the bone and lead to different biomechanical strength.

A surgical technique should aim for the best clinical result with the lowest complication rate. However, studies describing results of different techniques of TTO in terms of procedure specific complications are lacking, but it is essential to have knowledge on this for an optimal patient specific treatment plan.

Outcome measurement

The goal of treatment of patients with patellofemoral instability is to create a stable patella and decrease functional impairment and pain due to patellar instability. An obvious outcome measure is recurrent dislocation or instability of the patella. This objective outcome parameter is always described in studies reporting on conservative and/or surgical treatment of patients with patellofemoral instability. However, this objective outcome is not always the most critical in the perspective of a patient, who might value more subjective outcome such as functional impairment, inability to perform tasks of daily life and inability to participate in sports both caused by the instability and the concomitant pain. Measuring only recurrent dislocation, could lead to a false good objective outcome, while the subjective outcome (in the outcome domain pain for instance) might be worse than before treatment. Another issue that might influence the objective outcome recurrent dislocation the other way around (false worse objective outcome) is the risk of recurrent dislocation due to demographic risk factors such as age at first dislocation, number of previous dislocations and grade of trochlear dysplasia. Ignoring these risk factors and with that the natural course, might bias the objective outcome. In addition to objective outcome, subjective outcome can be measured by valid and reliable disease specific patient reported outcome measurements (PROMs), which currently lack in Dutch language for patients with patellofemoral disorders.

Outline dissertation

The issues described in this introduction illustrate the complexity in decision making for adequate treatment of patients with patellofemoral instability due to its multifactorial character. This thesis is built on knowledge and evidence from previous research on patellofemoral instability, both national and international. Major international developments on patellofemoral instability include the definition of anatomic and radiographic factors affecting patellar instability including trochlear dysplasia by Dejour in 1994[4], the description of the rationale for MPFL-reconstruction by Arendt in 2000s, the description of new trochleoplasty principles by Dejour[24] (1990) and Bereiter[25] (1994) and the description of the

anteromedial tibial tubercle transfer by Fulkerson[26] (1990). In Nijmegen Koëter, Tigchelaar and Rood performed and published PhD work on patellofemoral disorders under supervision of promotor Van Kampen. Koëter concluded that operative intervention can be indicated for recurrent patellar instability and that surgical correction should be aimed at the anatomic abnormality. Tigchelaar provided an overview of the epidemiology and etiology of patellofemoral dysfunction and increased insight into diagnosis and evaluation. Rood showed the optimal conservative treatment and benefits of a dynamic MPFL-reconstruction.

With an adequate MPFL-reconstruction technique as cornerstone of surgical treatment of patellofemoral instability, the question arises on the added value of osseous procedures in stabilizing the patella in patellofemoral surgery. The two types of osseous procedures that are frequently performed and address underlying anatomic abnormalities are the TTO and the trochleoplasty. This thesis aims to address some clinical questions relevant for the optimal surgical treatment, including these two osseous procedures, of patients with patellofemoral instability. The following research questions summarize the topics of this thesis:

Imaging (Chapter 2)

1. What is the intra- and interrater reliability for different patellar height measurement methods on conventional radiography, CT and MRI? (Chapter 2)

Patellar height is a well-known anatomic risk factor for recurrent patellar instability and one of the indications for TTO. Measurement of patellar height should be included in the diagnostic workup for treatment of patellar instability. Several measurement methods and imaging modalities are in use. It is still under debate which measurement method is most reliable and which cutoff value is considered abnormal on different imaging modalities. Chapter 2 determines the intra- and interrater reliability for five different patellar height measurements on three different imaging modalities (CR, CT, MRI).

Tibial tubercle osteotomy (Chapter 3, 4)

2. What is the incidence of postoperative complications, specifically fracture and non-union, after a self-centering tibial tubercle osteotomy? (Chapter 3)

3. What is the incidence of postoperative complications, specifically fracture and non-union, after a V-shaped tibial tubercle osteotomy? (Chapter 4)

Serious complications that are specifically related to an osteotomy include fracture and non-union. The short- and long-term results of the self-centering sliding tibial tubercle osteotomy (TTO) have been described previously. Good clinical results, low pain scores and a low amount of recurrent instability were demonstrated.

In Chapter 3 we quantify the risk of procedure specific serious complications of the self-centering sliding TTO in a large case series including 529 procedures.

Chapter 4 reports the rate of complications of a V-shaped TTO in a case series of 263 procedures. This is an essentially different technique, where the tibial tubercle is completely released from its periosteum using a V-shaped step-cut osteotomy.

Trochleoplasty (Chapter 5, 6, 7)

4. What is the effect of age on patient reported outcome after a lateral facet elevating trochlear osteotomy? (Chapter 5)

5. Do the clinical and radiological results of a lateral facet elevating trochlear osteotomy deteriorate in patients with a minimum of 12 year follow-up? (Chapter 6)

6. What is the rate of complications after various techniques used for trochleoplasty? (Chapter 7)

The lateral facet elevating trochlear osteotomy is historically one of the first described techniques of trochleoplasty. Concerns exist about the long term results of this procedure, it might lead to early patellofemoral osteoarthritis. This could be even more pronounced for older patients, because they are expected to have less pliable osteocartilaginous structures. In Chapter 5 we analyzed the effect of age on patient reported outcome of this type of trochlear osteotomy in a large cohort of 113 cases. In Chapter 6 we describe the clinical and radiological results of this surgical technique in patients with a minimum of 12 year follow-up.

Most articles on other trochleoplasty techniques present satisfactory results, although the outcome measures vary widely. However, complications are often not included as primary outcome measure. Chapter 7 assesses the rate of complications after various techniques used for trochleoplasty procedures. A systemic review of literature and a meta-analysis was performed. This provides more knowledge on complications after these procedures.

Outcome measurement (Chapter 8)

7. Are the translated Banff Patellar Instability Instrument and Norwich Patellar Instability score valid patient reported outcome measurements? (Chapter 8)

Outcome in terms of patellofemoral stability, patellofemoral osteoarthritis or complications are relatively easy to measure or document. However, it is clear that focusing on these 'objective' outcomes neglects the 'subjective' outcome experienced by the patient. So far, there is not a recipe to achieve an 'objective' good outcome that is a guarantee for a 'subjective' happy patient. To evaluate this more subjective outcome, patient reported outcome measures (PROMs) can be used. In previous years, two new English PROMs have been developed specifically for patients with patellofemoral disorders. In Chapter 8 we translated these PROMs to Dutch language. Then, they were validated in patients who have undergone surgical treatment for patellar instability.

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CHAPTER 2

PATELLAR HEIGHT MEASUREMENTS: INSALL-SALVATI RATIO IS MOST RELIABLE METHOD

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Abstract

Purpose

Patella alta is a risk factor for patellofemoral pain and instability. Several measurement methods and imaging modalities are in use to measure patellar height. The first aim of this study was to determine the intra-and interrater reliability of different patellar height measurement methods on conventional radiography (CR), CT and MRI. The second aim was to examine the applicability of patellar height measurement methods originally designed for CR on CT and MRI.

Methods

Forty-eight patients who were treated for patellar instability were included. All patients had undergone a pre-operative conventional radiograph, CT scan and MRI. Five methods for measuring patellar height were performed on radiographs, CT and MRI by four observers. For each measurement the intra- and interrater reliability was determined by calculating the intra-class correlation coefficient (ICC). A Bland Altman analysis was performed for measurements with an ICC $\geq$ 0.70.

Results

The Insall-Salvati (IS) ratio was the only measurement that showed good intra- and interobserver reliability on CR, CT and MRI. The intra- and interobserver reliability of the patellotrochlear index (PTI) for MRI was good to excellent for all observers.

The IS-ratio showed a moderate to good reliability for comparison of all three imaging modalities with the best agreement between radiography and MRI. The other patellar height measurements showed only poor to moderate inter-method agreement.

Conclusion

In this study the Insall-Salvati ratio shows better intra- and inter-observer reliability than the Blackburne-Peel ratio, the Caton-Deschamps ratio and the modified Insall-Salvati ratio on all imaging modalities. Radiography and CT seem to have better reliability than MRI. The patellotrochlear index however shows good inter- and intra-observer reliability on MRI.

Only for the IS method was there acceptable agreement between CR and MRI. This means that the established Insall-Salvati normal values could be used for MRI as well.

This study shows that the most reliable method to measure patella height is the Insall-Salvati ratio measured on conventional radiographs or the patellotrochlear index on MRI.

Keywords

Patellar height, inter observer reliability, radiography, CT, MRI.

Level of evidence

Level II diagnostic

Introduction

Patella alta is a well-known anatomic risk factor for recurrent patellar instability which may contribute to patellofemoral pain [12,15,34]. In patients with patellar instability or patellofemoral pain a measurement of patellar height should be included in the workup for treatment because surgical correction of patellar height might be indicated. To measure patellar height several measurement methods and imaging modalities are in use. Measurement methods include the Insall-Salvati ratio (IS) [21], Blackburne-Peel ratio (BP) [7], Caton-Deschamps ratio (CD) [10], modified Insall-Salvati ratio (MIS) [19] and patellotrochlear index (PTI) [5] (Fig. 1). Unfortunately, there is still no consensus in literature on measurement method or cutoff value as shown by Biedert et al [6] in their recent review of patellar height measurement methods.

Widely used imaging modalities are conventional radiography (CR), computed tomography (CT) and magnetic resonance imaging (MRI). Recently however Giovagnorio et al [17] proposed ultrasound as a good imaging modality to measure patellar height, reducing the need for other imaging techniques. IS, BP, CD and MIS were originally designed for measurement on CR. These methods could also be applied to CT or MRI images, in which case different normal values might be used. Lee et al. [23] present normal values for IS and BP for different imaging modalities. These have not been described for MIS and CD to our knowledge. Apart from the confined amount of literature describing normal values for CT and MRI, there is also a lack of descriptions of standardized measurements of patellar height on these imaging modalities. The measurement technique differs from measurement on CR, among other things because of the presence of slices on CT and MRI. Shabshin et al. [32] describe a method to standardize the choice for a slice to measure patellar length and patellar tendon length. It is not known if this is a reliable method between observers or if it is applicable to all measurement methods, and it is time consuming to apply this in daily practice. Barnett et al. [3] describe good inter- and intra-observer reliability for IS, BP, CD and PTI on MRI. However, their choice of slice on MRI is based on the PTI, which was specifically designed for measurement of patellar height on MRI using the femur as a reference point. This is in contrast to IS, MIS, CD and BP where the tibia is used as reference. Ali et al. [1] and Barnett et al. [3] describe that the PTI does not correlate well with other patellar height measurements. Therefore, this might not be a good way to choose a slice on which to perform other patellar height measurements.

The aim of this study was to determine the intra-and interrater reliability for different patellar height measurement methods (IS, BP, CD, MIS originally designed for CR) on CR, CT and MRI. This includes the intra-and interrater reliability for the PTI on MRI. It was hypothesized that there might be significant variability in measurement results between measurements and between imaging modalities.

Materials and methods

All patients over 18 years of age who were treated in our hospital for patellar instability between May 2015 and April 2017 who had pre-operative CR, CT and MRI imaging of the knee were included in this study. This resulted in 48 patients. Forty-six patients had a pre-operative CR, CT scan and MRI of one knee and two patients had all imaging done on both knees pre-operatively. Eight patients had a patella alta on account of all measurements on radiographs, 19 patients had normal patella height and 21 patients had patella height that varied between the four measurement methods using radiography.

Measurements

Five different methods for measuring patellar height were used: the Insall-Salvati ratio (IS)[21], the Blackburne-Peel ratio (BP)[7], the Caton-Deschamps ratio (CD) [10], the modified Insall-Salvati ratio (MIS)[19] and the patellotrochlear index (PTI) [5] (Fig 1.).

Measurements were performed as follows:

Insall-Salvati ratio: Ratio of the length of the patellar tendon (measured from the distal pole of the patella to the tibial tuberosity) to the maximum length of the patella (measured from the distal pole to the proximal pole of the patella).

Blackburne-Peel ratio: Ratio of the height of the distal pole of the patellar articular surface above a tibial plateau line to the articular surface length of the patella.

Caton-Deschamps ratio: Ratio of the distance between the anterosuperior point of the tibial plateau and the distal pole of the patellar articular surface to the articular surface length of the patella.

Modified Insall-Salvati ratio: Ratio of the distance between the distal pole of the patellar articular surface and the tibial tuberosity to the articular surface length of the patella.

Patellotrochlear index: Overlap percentage of the trochlear cartilage (measured from the superior most aspect of trochlear cartilage with respect to the inferior most aspect of the articular patellar cartilage using a right angle and parallel lines) and the articular cartilage of the patella.

IS, BP, CD and MIS were measured on conventional radiographs, CT and MRI. The PTI was measured on MRI as it was specifically developed for this imaging modality.

All measurements and ICC were reported with two decimals. Bland Altman was reported using three decimals.

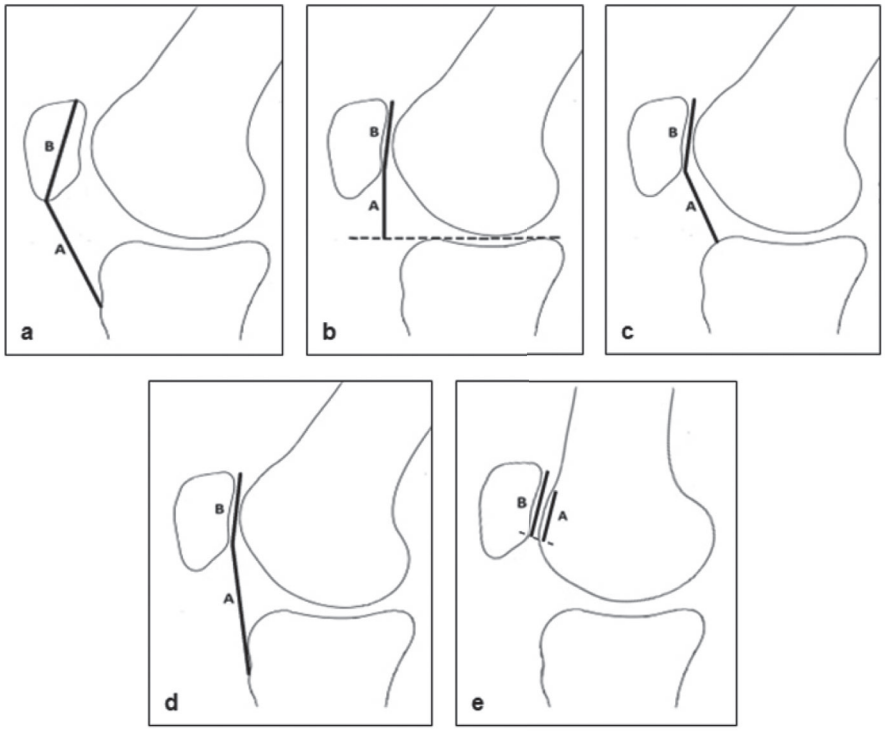

Figure 1. Patellar height measurement methods

a: Insall-Salvati ratio: Ratio of the length of the patellar tendon (measured from the distal pole of the patella to the tibial tuberosity) (A) to the maximum length of the patella (measured from the distal pole to the proximal pole of the patella) (B).

b: Blackburne-Peel ratio: Ratio of the height of the distal pole of the patellar articular surface above a tibial plateau line (A) to the articular surface length of the patella (B).

c: Caton-Deschamps ratio: Ratio of the distance between the anterosuperior point of the tibial plateau and the distal pole of the patellar articular surface (A) to the articular surface length of the patella (B).

d: Modified Insall-Salvati ratio: Ratio of the distance between the distal pole of the patellar articular surface and the tibial tuberosity (A) to the articular surface length of the patella (B).

e: Patellotrochlear index: Overlap percentage of the trochlear cartilage (measured from the superior most aspect of trochlear cartilage with respect to the inferior most aspect of the articular patellar cartilage using a right angle and parallel lines) (A) and the articular cartilage of the patella (B).

Observers

Four observers with different medical experience performed all of the measurements mentioned above on radiograph, CT and MRI in 2 cycles with a minimum of 4 weeks apart. The four observers included an orthopedic surgeon, a radiologist, an orthopedic resident and a medical student.

IRB approval was received from the review board of Canisius Wilhelmina Hospital, Nijmegen, The Netherlands, ID number: 039-2017.

Statistical analysis

For each measurement (IS, BP, CD and MIS on CR, CT and MRI) the intra- and interrater reliability was determined by calculating the intra-class correlation coefficient (ICC). To compare results of the IS, BP, CD and MIS measurements between CR, CT and MRI (inter-method reliability) an ICC was also calculated. The ICC estimates the average correlation among pairs of data and gives a value between 0 and 1.

Scores were interpreted as follows: a score of 0 to 0.50 indicating poor reliability, 0.50 to 0.75 indicating moderate reliability, a score of 0.75 to 0.90 indicating good reliability, and a score higher than 0.90 indicating excellent reliability [29].

The ICC is a qualitative measure of reproducibility. In order to further quantify the reliability of the measurements the Bland Altman analysis was used to assess agreement [2]. It evaluates the mean difference in measurements and a range of agreement within which 95% of the differences between one measurement and the other are included. A Bland Altman analysis was performed for measurements with an ICC $\geq$ 0.70. A mean difference $<$0.20 on the different measurement methods was deemed acceptable for clinical use.

SPSS software (version 24.0, SPSS Inc., Chicago, IL, USA) was used to calculate the intra-class correlation coefficients and Microsoft Office Excel (version 14.0, Microsoft Corp., Redmond, WA, USA) was used for all Bland Altman analyses calculating mean differences and limits of agreement.

We included all patients who had all three imaging modalities available in the selected time frame. In a review article, Bujang et al. [9] provide a guide to determine the minimum sample size required for estimating the desired effect size of ICC. According to this guide, the minimum sample size requirement for our study is 25 subjects when alpha is pre-specified to be 0.05, power to be 0.90, an acceptable ICC of 0.70 and an expected ICC of 0.9.

Results

Of the 48 patients, 11 were male and 37 were female. Median age was 22 (18-51) years. The radiographs and scans were of variable quality because some of these patients were referrals from other hospitals where imaging had already been performed. However, none of the scans needed to be rejected due to poor quality.

Table 1 shows the minimum and maximum ICC values for intra-observer reliability of each measurement.

The IS was the only measurement that had a moderate to good or excellent intra-observer reliability on CR (0.72 – 0.91), CT (0.78 – 0.83) and MRI (0.70 – 0.85). The intra-observer reliability of the PTI for MRI was good to excellent for all observers (0.81 – 0.91). The lowest intra-observer reliability was seen with the other MRI measurements (BP 0.42 – 0.73, CD 0.26 – 0.84, MIS 0.18 – 0.76). Of all observers the radiologist scored the best overall intra-observer reliability. The overall ICC's of the medical student however were clearly lower than those of the other three observers. To include these measurements in the calculation of inter-observer reliability would significantly alter and cloud the final inter-observer reliability results. For this reason, and because in every day practice these measurements are not done by students, the results of the medical student were excluded from calculating the ICC's for inter-observer reliability.

	CR	CT	MRI
IS	0.72 (0.56 - 0.83)	0.78 (0.65 - 0.87)	0.70 (0.53 - 0.82)
	0.91 (0.83 - 0.95)	0.83 (0.72 - 0.90)	0.85 (0.60 - 0.93)
BP	0.63 (0.42 - 0.77)	0.38 (-0.07 - 0.67)	0.42 (-0.24 - 0.32)
	0.80 (0.67 - 0.89)	0.84 (0.73 - 0.90)	0.73 (0.33 - 0.88)
CD	0.71 (0.54 - 0.83)	0.67 (0.49 - 0.80)	0.26 (0.00 - 0.49)
	0.84 (0.67 - 0.91)	0.83 (0.71 - 0.90)	0.84 (0.64 - 0.92)
MIS	0.48 (0.07 - 0.72)	0.48 (0.21 - 0.67)	0.18 (-0.10 - 0.44)
	0.73 (0.56 - 0.83)	0.85 (0.74 - 0.91)	0.76 (0.57 - 0.87)
PTI	--	--	0.81 (0.70 - 0.89)
			0.91 (0.84 - 0.95)

Table 1. Intra-observer reliability: ICC min/max values (CI 95%)

Table 2 shows the ICC's for inter-observer reliability of each measurement. The inter-observer reliability was good for IS measurements on CR (0.80), CT (0.75) and MRI (0.78). The overall ICC was moderate to good for CR and CT. The PTI showed good inter-observer reliability (0.80), however ICC for BP, CD and MIS was poor on MRI (0.09, 0.41 and 0.27 resp.).

	CR	CT	MRI
IS	0.80 (0.72 - 0.87)	0.75 (0.66 - 0.83)	0.78 (0.69 - 0.85)
BP	0.70 (0.60 - 0.80)	0.72 (0.61 - 0.81)	0.09 (0.01 - 0.21)
CD	0.76 (0.67 - 0.84)	0.72 (0.61 - 0.82)	0.41 (0.22 - 0.59)
MIS	0.61 (0.49 - 0.73)	0.69 (0.59 - 0.79)	0.27 (0.16 - 0.41)
PTI	--	--	0.80 (0.69 - 0.88)

Table 2. Inter-observer reliability: ICC (CI 95%)

The ICC for inter-method reliability was calculated using measurements of the radiologist because those had the highest intra-observer reliability. However, when using the measurements of the orthopedic surgeon or resident the results were similar. The IS method showed a moderate to good ICC for comparison of all three modalities with the best agreement between radiograph and MRI. The MIS method showed a poor agreement between CR, CT and MRI (Table 3).

	CR/CT	CR/MRI	CT/MRI
IS	0.77 (0.66 - 0.86)	0.86 (0.77 - 0.92)	0.70 (0.51 - 0.82)
BP	0.49 (0.30 - 0.66)	0.54 (0.40 - 0.68)	0.62 (0.46 - 0.75)
CD	0.63 (0.50 - 0.74)	0.64 (0.49 - 0.76)	0.61 (0.48 - 0.73)
MIS	0.58 (0.44 - 0.71)	0.20 (0.07 - 0.36)	0.28 (0.15 - 0.44)

Table 3. Inter-method reliability: ICC (CI 95%)

	OS versus RA	OS versus OR	RA versus OR
CR			
IS	0.051 (± 0.164)	0.079 (± 0.208)	0.062 (± 0.144)
BP	0.079 (± 0.184)	0.071 (± 0.163)	0.071 (± 0.139)
CD	0.059 (± 0.182)	0.073 (± 0.185)	0.056 (± 0.146)
CT			
IS	0.061 (± 0.162)	0.063 (± 0.165)	0.066 (± 0.168)
BP	0.057 (± 0.156)	0.091 (± 0.211)	0.095 (± 0.187)
CD	0.052 (± 0.195)	0.095 (± 0.191)	0.113 (± 0.206)
MRI			
IS	0.046 (± 0.132)	0.079 (± 0.182)	0.078 (± 0.175)
PTI	4.78% (± 12.90%)	8.31% (± 14.44%)	8.84% (± 14.90%)
OS: Orthopedic Surgeon, RA: Radiologist, OR: Orthopedic Resident			

Table 4. Degree of agreement between observers according to Bland Altman analysis: Mean differences (limits of agreement)

Cut-off points were used to classify the ICC's for intra- and inter-observer and inter-method reliability, but an ICC remains a qualitative measure. Regarding inter-observer and inter-method reliability it was hypothesized that an ICC of 0.70 could also be high enough to ensure good reliability. To quantify this, a Bland Altman analysis was performed for all measurements with an ICC of 0.70 or higher. Results are shown in table 4.

The results of Bland Altman analyses for inter-method reliability of the IS measurement are not displayed in a table but were 0.084 (± 0.182) for CR versus CT, 0.059 (± 0.122) for CR versus MRI and 0.101 (± 0.209) for CT versus MRI.

Discussion

The most important finding of the present study was that the inter- and intra-rater reliability was good for the Insall-Salvati (IS) ratio on all imaging modalities and for the patellotrochlear index (PTI).

Smith et al. [33] researched intra observer reliability for different patellar height measurements on CR and found the reliability of CD to be better than BP and IS. This is in contrast to the current study where the IS method had the best intra-observer reliability compared to CD, BP and MIS. This was not only the case for CR but for CT and MRI as well. Smith et al. [33] also propose that the intra-observer reliability of a measurement method may be related to experience, which is what this study showed as well. The ICC's for intra-observer reliability of the different measurements conducted by the medical student were generally lower than those of the orthopedic resident, the orthopedic surgeon and the radiologist.

Barnett et al. [3] in their study of different patellar height measurements on MRI found a good intra observer reliability for IS, BP, CD and PTI on MRI. The current study also showed good intra observer reliability for IS and PTI on MRI, however BP, CD and MIS showed poor reliability. Different observers may choose a different sagittal slice on different occasions which leads to a decreased intra- and interobserver reliability. Most authors report the use of the mid-sagittal slice to perform measurements [3, 23, 24], but in patellar instability patients this is rarely the slice with the maximal length of the patellar bone, tendon or cartilage. Due to the fact that the patella is often lateralized, this will lead to different interpretations of which slice is the most accurate to perform measurements, when for example on one slice the cartilage is thickest and on another the patellar length is highest. So differences in interpretation of cartilage thickness, patellar length and 3D configuration might give rise to different measurement results. Having more experience with these measurements will increase uniformity of the observer and as a consequence increase the intra-observer reliability. The results of the medical student, later excluded from the results, confirm that experience is needed for adequate measurements; these measurements cannot be done reliably by unschooled personnel.

With regard to the inter observer reliability, both Van Duijvenbode et al.[13] and Gracitelli et al. [18] found the IS to have the best agreement on CR compared to CD, BP and MIS, which is what this study showed as well. Although Van Duijvenbode et al. [13] advise to use the MIS rather than IS because of better validity. Chareancholvanich et al. [11] described ICC values for inter observer reliability similar to this study, with the IS method being the most reproducible. Kar et al. [22] even found that a clinical measurement of the Insall-Salvati index was not statistically significant different from a radiological IS measurement. Lee et al. [23] found excellent ICC's not only for IS but also BP on all imaging modalities. However, both Seil et al. [31] and Berg et al. [4] found the BP ratio to be the most reliable on CR. Alternatively, Philips et al. [27] in their extensive review of patellar height measurements rule the BP and CD to be the most reliable radiographic techniques.

Barnett et al. [3] describe good inter observer reliability for IS, BP, CD and PTI on MRI and Munch et al. [25] found high inter observer reliability for BP, CD and MIS on MRI (0.78-0.87). In the current study however only IS and PTI showed good inter observer reliability on MRI. These observations show that there are quite a few discrepancies in the literature about the reliability of measuring patellar height. IS and BP seem to alternate as most reliable, however in this study IS was undoubtedly better based on the ICC.

Biedert et al. [5] also found the inter observer correlation of the PTI to be high and significant. This is supported by Ali et al. [1] and Barnett et al. [3], however they found that the PTI did not correlate well with other patellar height measurements on MRI. Munch et al. [25] found a good correlation between PTI and CD and between PTI and BP. The current study was not designed to look at the correlation between different measurement methods on MRI, but it seems literature is divided on this matter.

The second aim of this study was to investigate the applicability of established normal values of patellar height measurements for CR on to CT and MRI. The IS method showed a moderate to good reliability for comparison of all three modalities with the best agreement being between radiography and MRI. The other patellar height measurements showed only poor to moderate agreement between CR, CT and MRI. One explanation for this could be that the IS a measurement method with only bony references. Therefore, this might be more consistently measured on different imaging modalities, in contrast to cartilage which is not visible on either CR or CT.

If a correlation between methods is found it does not necessarily mean that measurements methods agree in outcome. The Bland Altman analysis evaluates if there is a bias between mean differences between measurement methods and estimates a limit of agreement [16]. When looking at the mean differences between the radiologist and the orthopedic surgeon the largest mean difference

is 0.079, for BP on CR, which is within the acceptable range (<0.2). However, the limits of agreement are >0.2 for all measurements except IS on MRI, but they all include 0. In conclusion, the mean differences between experienced observers are acceptable for clinical use (<0.2), but one should be aware of a possible disagreement when interpreting IS, BP, CD, MIS on CT or MRI.

Lee et al. [23] described a good correlation between CT and MRI for the IS method. The current study showed good correlation and acceptable limits of agreement for MRI but unacceptable limits of agreement for CT, although this was still better than the BP, CD and MIS methods. Based on these findings it would be unwise to adopt normal values for radiographs on to CT but they could be used for MRI. If one wishes to use CD, BP and MIS methods both conventional radiographs and a scan have to be ordered to fully assess the patellofemoral anatomic morphology.

Both Lee et al. [23] and Miller et al. [24] describe an adjustment on established normal values for radiographs to create new normal values that can be used for CT and MRI. A new set of normal values could not be calculated in this study because instead of a normal population the current study group consists only of patients with patellofemoral symptoms and pathological patellofemoral anatomy.

Over the years, numerous methods of measuring patellar height have been developed. Subsequently there is a fair amount of literature available comparing the various measurement methods and testing the reliability of these methods [6]. With easier access to CT and MRI nowadays new methods are being developed specifically for MRI. As well as options for transferring normal values for x-ray onto CT or MRI are being explored.

The measurement of patellar height is widely researched in literature but with varying outcomes. However, in the current study all the above-mentioned factors have been combined and everything was tested under the same circumstances, making the outcomes more reliable. Only Lee et al [23] so far has compared patellar height methods between x-ray, CT and MRI, but they only tested the Blackburne-Peel and Insall-Salvati indices. Yue et al [35] in their recent study did compare the Insall-Salvati, modified IS, Caton-Deschamps and Blackburne-Peel indices but used only radiograph and MRI as imaging modalities.

Some promising patellar height measurements that were not included in this study are the patella-plateau angle [28]. It's reliability and reproducibility in patients with patellofemoral instability has been published recently [8]. Previously it was only used in osteoarthritic patients [14] and in patients with a total knee arthroplasty [30].

Also, Nizić et al. [26] propose a new reference line for diagnosing patella alta that is simple, accurate and reproducible, with a 100% binary intra- and inter-observer agreement. Hanada et al. [20] found the Modified Blumensaat line to be a valid and applicable patellar height measurement with a knee flexion angle

of 30-40˚ on conventional x-ray. They state that a patellar height measurement that utilizes a femoral reference point is better than a tibial based method when patella alta is suspected. According to them a patellar height measurement that utilizes a femoral reference point would be more suitable when patellofemoral joint pathology due to patellar height is considered.

A possible limitation of this study could be that a lot of the conventional radiographs were not perfect lateral views. Also, the scans were of variable quality because they came from a variety of hospitals. This could result in imperfect measurements; however it was decided not to change this because it is what best represents daily practice in most hospitals.

With literature being divided on the best way to measure patellar height, clinicians are using many different methods. As for any clinical measurement, in order to accurately communicate between clinicians, define indications for surgery or do clinical research, it is important to have a gold standard. With most clinicians having accessibility to CT and/or MRI nowadays, it is important for that gold standard measurement method to be applicable to multiple imaging modalities.

Conclusion

In this study the Insall-Salvati ratio shows better intra- and inter-observer reliability than the Blackburne-Peel ratio, the Caton-Deschamps ratio and the modified Insall-Salvati ratio on all imaging modalities. Radiography and CT seem to have better reliability than MRI. The patellotrochlear index however shows good inter- and intra-observer reliability on MRI.

Only for the IS method is there acceptable agreement between CR and MRI. This means the established Insall-Salvati normal values could be used for MRI as well.

This study shows that the most reliable method to measure patella height is the Insall-Salvati ratio measured on conventional radiographs or the patellotrochlear index on MRI.

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CHAPTER 3

COMPLICATIONS OF A SELF-CENTERING SLIDING TIBIAL TUBERCLE OSTEOTOMY FOR PATELLOFEMORAL COMPLAINTS; LOW INCIDENCE OF NON-UNION AND FRACTURE

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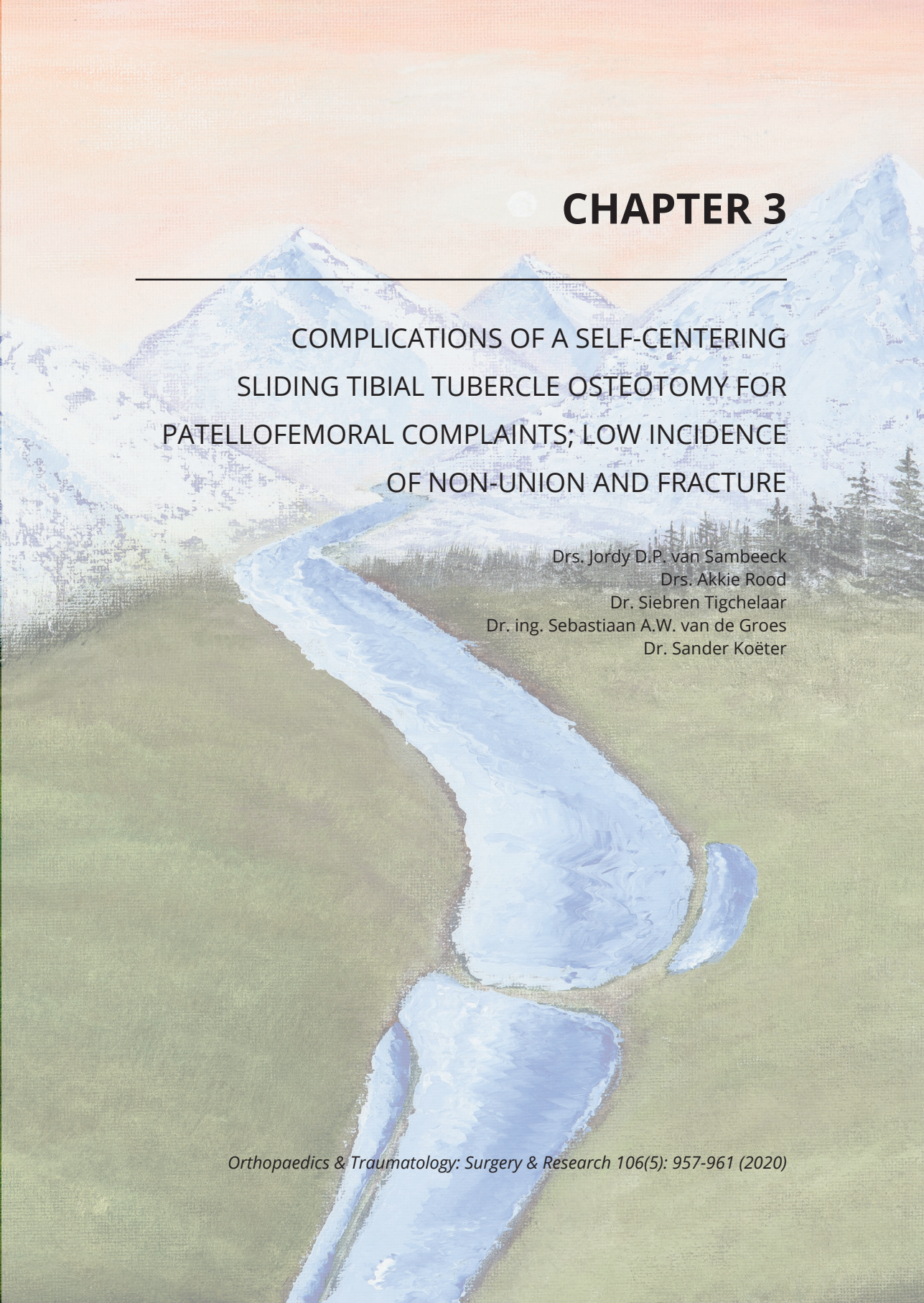

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Abstract

Background
A tibial tubercle osteotomy (TTO) is a commonly performed procedure in young and active patients with patellofemoral complaints. Previous small patient series demonstrated a relatively high risk of complications, which appear to be technique dependent. The purpose of this large case series is to quantify the risk of procedure specific postoperative complications related to a uniform self-centering TTO technique in a large cohort, performed by two different surgeons in one center.

Hypothesis
We hypothesize that non-union or fracture occurs in less than 1% of the procedures.

Patients and methods
Five hundred and twenty-nine knees in four hundred and forty-seven patients who underwent a self-centering TTO with at least one year of follow up were included. We performed a retrospective cohort review. Tibial fracture, osteotomy non-union, neurovascular complications, infection and wound complications that required surgical intervention were defined as major complications, miscellaneous complications were defined minor.

Results
The major finding in this study is the low incidence of non-union (0.6%) and tibial fracture (0.4%). In total 9 (1.7%) major complications were reported**.** Minor complications included superficial wound infection in five patients, two patients had a venous thrombo-embolism (VTE).

Conclusion
A self-centering TTO is a relatively safe technique with a low number of nonunion and fracture.

Level of evidence
Level IV, retrospective cohort study

Key words
Patella, Patellofemoral joint, Patellar instability, Patellofemoral pain, Tibial tubercle osteotomy

Introduction

A tibial tubercle osteotomy (TTO) is used to correct patella alta or an increased tibial tubercle trochlear groove distance (TT-TG) in young patients with severe patellofemoral complaints. With a distalization or medialization of the tibial tubercle the anatomical abnormalities can be addressed. This increases patellofemoral stability and decreases abnormal patellofemoral contact pressures [1]. Different techniques for TTO have been described. Frequently used current methods are the modified Elmslie-Trillat medialization technique [2], the Fulkerson anteromedialization technique [3] and techniques in which the tibial tuberosity is completely detached. The recent review by Payne et al.[4] concluded that the risk of complications is related to the employed technique. In his review some techniques had a complication rate as high as 10.7%, whereas others had lower complications rate of 3.3%. Previously, the short- and long-term results of a self-centering technique were published [5, 6]. We perform a lateral osteotomy in the frontal plane to guarantee that there is no anterior or posterior displacement. After temporarily distal fixation with an AO 2.5 mm drill bit, the tibial tubercle will centralize to its neutral position in 90 degrees of flexion of the knee. Authors demonstrated good clinical results, low pain scores and a low amount of recurrent instability and only marginal increase of radiological signs for patellofemoral osteoarthritis at ten years after this procedure [6].

Altogether, the previous literature indicates that there is a serious risk of either early or late complications after TTO. However, most previous studies are based on small case series, which might lead to false conclusions, because observations can be due to chance. The largest cohort is described by Cox et al. and included 116 procedures in 104 patients[2], other series ranged from 18 to 62 patients[4]. The purpose of this large case series is to quantify the risk of procedure specific postoperative complications related to a uniform self-centering TTO technique performed by two different surgeons in one center. We hypothesize that non-union or fracture occurs in less than 1% of the procedures.

Patients and methods

All patients who underwent either an isolated self-centering sliding TTO or a TTO procedure combined with a medial patellofemoral ligament reconstruction (MPFL) and/or a trochlear osteotomy between May 2008 and November 2016 with at least one year of follow up were included. Indications for TTO were recurrent patellar dislocations or instability, persistent patellofemoral pain with anatomic abnormalities or post traumatic patella abnormality (patella alta after ruptured patellar tendon, patella baja after an anterior cruciate ligament reconstruction). All patients had closed epiphyseal growth plates. Data on complications was collected prospectively, all patient charts were retrospectively reviewed to check for completeness. Patients who were treated for patellar instability after a prior

total knee arthroplasty (TKA) were excluded from analysis. All procedures were performed by two experienced orthopedic surgeons.

Complications related to the surgical procedure were classified as minor or major, according to the criteria used in Payne's review article [4]. Major complications were defined as tibial fracture, osteotomy non-union, neurovascular complications and infection and wound complications that required surgical intervention. The scope of this article is to focus on complications specifically related to the bony procedure, being for example delayed union, nonunion, fractures and hardware removal. Complications which might also have a relation with additional procedures, such as infection, arthrofibrosis and thrombo-embolic events are addressed, but are not the main focus.

Surgical technique and postoperative care:

The surgical technique that was performed is previously described [5, 6] (figure 1). A lateral osteotomy of the tibial tubercles is performed in the frontal plane, the osteotomy is 5 cm in length and 0.75 cm thick. The medial soft tissue is released, but remains attached to the tubercle. In patients with patella alta, the patella is moved distally. The tubercle is then temporarily fixed with an AO 2.5 mm drill bit at its distal end, the knee is then flexed to 90°. The tibial tubercle will automatically rotate and align to its 'neutral' position due to the pull of the extensor apparatus and is then fixed with screws. Additional simultaneous procedures such as an MPFL reconstruction and/or trochleoplasty were performed when indicated. Post-operative care consisted of a removable brace with the knee in full extension for six weeks. Full weight bearing was allowed as tolerated whilst wearing the brace and full range of motion was advised without bearing weight. A low-molecular-weight heparin was prescribed during the first six weeks. Follow-up of these patients was routinely six weeks post operatively and 6 months after surgery at outpatient clinic of the surgeon who performed the surgery. On indication (e.g. when delayed or non-union at 6 months), the follow-up was longer.

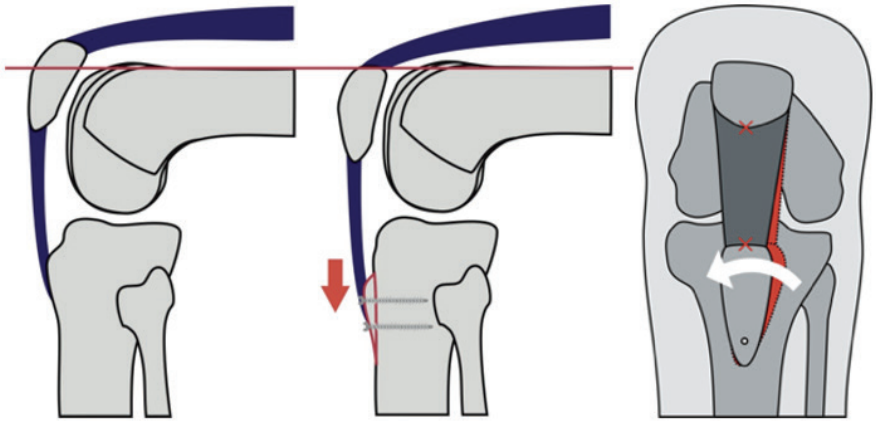


Figure 1. Surgical technique. A lateral osteotomy in the frontal plane is performed, about 5 cm long and 0.75 cm thick. Medial soft tissues remain intact to the tuberosity. Patellar height can then be adapted and the tibial tuberosity is fixed temporarily, then the knee is flexed tot 90 degrees. This centers the patella between the distal femoral condyles, causing the patella tendon to center the tibial tuberosity. In this position the tuberosity is fixed with two or three lag screws.

Statistical analysis:

A Chi-square test was used to detect differences in major and minor complications between sexes, whether or not patients had previous surgery, whether or not additional procedures were performed and between indications pain and instability. Fisher´s exact test was used if the observed value was 10 or lower or when expected count was equal to or lower than 5 with Chi-square analysis. If a complication occurred less than five times, no analysis was performed. Statistical analyses were performed using the statistical package SPSS 20.0 for WINDOWS (IBM SPSS, Chicago, IL, USA).

Results

Five hundred and twenty-nine (529) knees in four hundred and forty-seven (447) patients were included in analysis. Two patients with patellar dislocation after a prior TKA were excluded. Descriptive statistics are displayed in table 1.

Patient characteristics	
Number of patients	437
Number of knees	529
Mean age (range)	23.2 (13.8-59.9)
	N patients (%)
Female (%)	389 (74)
Indication	
Patellofemoral pain	171 (32.3)
Patellofemoral dislocations	249 (47.1)
Miscellaneous	2 (0.4)
Previous procedures performed	
None	436 (82)
Arthroscopy	41 (7.8)
MPFL reconstruction	15 (2.8)
T ibial tubercle transposition	7 (1.3)
with lateral release	9 (1.7)
VMO-plasty	3 (0.6)
Trochleoplasty	1 (0.2)
Miscellaneous	9 (1.7)
Additional procedures performed	
None	227 (43)
MPFL reconstruction	248 (47)
Trochleoplasty and MPFL reconstruction	53 (10)
Lateral lengthening	16 (3.0)

Table 1. Descriptive statistics

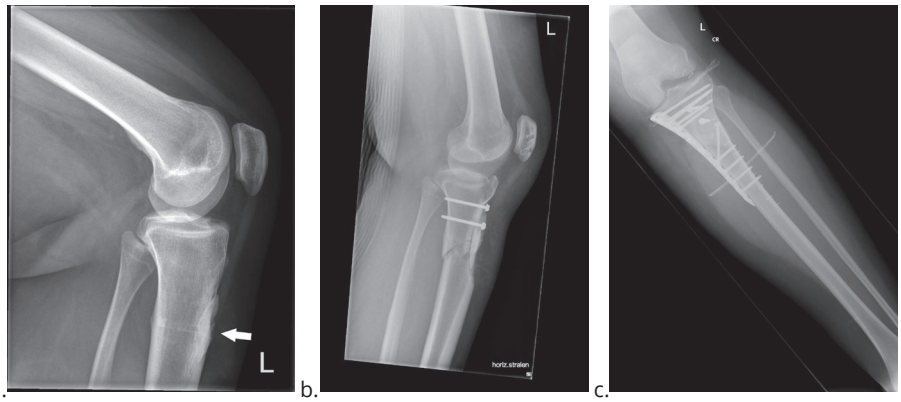
Major complications related to the surgical procedure were reported in 9 patients (1.7%) and are presented in table 2. These major complications included: one tibial fracture at the site of a large AO screw of a prior tibial tubercle osteotomy performed elsewhere requiring internal plate fixation (figure 2a-c) and one patient with a fracture of the tibial tubercle after a fall from the stairs 3 months postoperatively requiring open reduction and internal fixation (figure 3a-c). A nonunion was observed in three patients (0.6%), of whom two required subsequent surgery and one was treated with 6 additional weeks of cast immobilization (figure 4a-c). One patient suffered a deep wound infection which required surgical debridement and one patient suffered a low-grade infection which was arthroscopically debrided. In two patients a large hematoma was surgically evacuated. Minor complications included superficial wound infection treated with antibiotics in five patients.

Wound infection was more common in patients who had previous surgery performed (P<0.05). Two patients had a venous thrombo-embolism (VTE), they were treated with a direct oral anticoagulant for three months. There were no minor complications specifically related to the TTO.

Screws were removed after consolidation of the osteotomy in 47% of the cases. Indications for screw removal were compression pain at the screws or at patient demand. Screws were removed more often in female than in male patients (53% vs. 29% respectively, odds ratio 2.69, P<0.05) and in patients with patellofemoral pain prior to surgery (54% vs. 28%, P<0.05). Nine patients had a reduced ROM requiring manipulation under anesthesia.

Results	**N**
Major complication	
Nonunion	3
Fracture	2
Deep infection	2
Wound complications	2
Minor complication	
Superficial infection	5
Tromboembolic event	2

Table 2. Number of complications



a. b. c.

Figure 2a-c
Conventional radiographs of a patient who sustained a tibial fracture:
a. preoperative X-ray where a drill hole of a screw of a prior tibial tubercle osteotomy can be seen (arrow).
b. fracture at the site of the drill hole.
c. postoperative X-ray after treatment of the fracture with internal plate fixation

Discussion

In this study, we describe the risk on complications in a large cohort of patients with a tibial tubercle osteotomy (TTO). The major findings of this study are the low incidence of non-union and tibial fracture after a self-centering technique of tibial tubercle transposition in a large cohort. The rate of nonunion in this cohort (0.6%, 3/529 procedures) is slightly lower than the incidence Payne et al.[4] reported in their systematic review (0.8%, 6/787 procedures). Two patients (0.4%) sustained a postoperative fracture, one of the tibia and one of the tibial tuberosity. In Payne's review article the rate of fracture was 1.0%. The rate of non-union and fracture together is slightly lower than 1%, which confirms our hypothesis.

We believe the non-union rate is related to the technique. When only the lateral periosteum is transected in order to make the osteotomy and the medial and distal periosteum remains intact, the blood flow decreases 25%. If a complete detachment of the tibial tubercle is performed and the medial, lateral and distal periosteum is transected, this leads to a complete arrest of the blood flow[7] and a higher chance of non-union.

Fractures seem to be caused by mechanical issues. With this technique tibial fracture is rare. In other series fractures did occur, both acute and delayed [5, 8-12]. In a previous article[5] two fractures occurred (one acute and one late in a cohort of 29 patients) when a step cut osteotomy (such as employed in total knee arthroplasty) was used, this produced a stress riser in the tibia and weakens the cortex. This can also lead to late fractures, usually a few months after surgery caused by bone fatigue induced by altered tibial biomechanics. In this series only one tibia fracture occurred at the site of a removed large AO fragment screw hole from a previous osteotomy in a revision case. Large fragment screw might have a higher change of fracture after removal then small fragment screws because of cortical weakening. In retrospect perhaps a staged approach would have been wiser, with removal of the screws first and a TTO only after complete bone healing. Another patient had a split fracture of the tibial tubercle after fall from the stairs. Despite the trauma as contributing factor, lessons that can be learned from this case is to avoid placing screws close to each other and to avoid placing them in one line.

Post-operative infections were seen in seven patients (1.3%) with 2 deep infections and 5 superficial wound infections. This is comparable to the rate of infection in the systematic review of Payne et al.[4]. In most of the reviewed articles by Payne[4] only patients with primary surgery were included, while in our cohort infection was more often seen in patients who had previous surgery.

None of the patients who had an isolated TTO had decreased ROM, but a decreased ROM was observed in nine patients with additional procedures, such as a MPFL and/or trochlea osteotomy implicating that the cause of the decreased ROM is intra articular fibrosis (arthrofibrosis) induced by intra- or periarticular surgery.

These findings are in line with results published in previous literature, describing a higher change of decreased ROM after all types of trochlea osteotomy and after MPFL reconstruction [13-15]. Patients with preoperative patellofemoral pain and female patients had a higher chance of postoperative hardware removal.

Depending on imaging alone for the degree of correction, has a risk of overcorrection of the tibial tubercle in medial direction, which might lead to medial dislocations or hypothetically to higher joint pressure and consequently early patellofemoral osteoarthritis. To prevent overcorrection, other authors use different intra operative measurements. Recently Arendt described a new physical exam measurement, the tubercle-sulcus angle (TSA), which can be performed in the operating room[16]. With a self-centering sliding technique overcorrection in medial direction is highly unlikely and intraoperative measurement are unnecessary. In our cohort, there were no postoperative medial dislocations. In a previous article on this technique, there was only a modest increase in radiological patellofemoral osteoarthritis of 0.35 with a maximum of grade 2 on the Kellgren-Lawrence scale at ten years follow up [6].

Limitations
The main weakness of this study is its design, a historical case series with heterogenic additional procedures. However, data on complications and recurrent dislocations were collected prospectively, and all patient records were reviewed to avoid data loss and prevent underestimation of early complications. Although it was not the goal of this study to evaluate patient reported outcomes, its absence is a weakness of the study. As well as the lack of postoperative CT or MRI to measure difference in TT-TG. A distinct advantage of this study is its large sample size, uniform technique of tibial tubercle osteotomy and protocolized postoperative care.

Competing interests

We have received no funding for this study and have no competing interests to declare.

Authors' contributions

JS and SK initiated the study by defining the research question and purpose of the study. JS performed data collection and analysis and drafted the manuscript together with AR. SK was the first author to review drafts of the manuscript and gave final approval of the version to be submitted. SG and ST were second reviewers of drafts of the article and added important feedback for interpretation of the results and for discussion section.

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CHAPTER 4

A DETACHING, V-SHAPED TIBIAL TUBERCLE OSTEOTOMY IS A SAFE PROCEDURE WITH A LOW COMPLICATION-RATE

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Abstract

Introduction
In patients with recurrent patellar dislocations, a tibial tubercle osteotomy (TTO) can be indicated to correct patella alta or an increased trochlear groove - tibial tubercle distance. Several surgical techniques are described. Previous studies emphasize that detaching osteotomies results in devascularisation, which can lead to non-union and tibial shaft fractures. The aim of this study was to report complication rates directly related to the surgical technique of a V-shaped TTO, where the tubercle is completely released from its periosteum using a step-cut osteotomy.

Methods
The retrospective case series comprised 263 knees in 203 patients who underwent a V-shaped TTO, with or without additional realignment procedures between March 2004 and October 2017. Data was obtained from available patient files. Complications were defined as minor or major.

Results
Thirteen major complications were registered (4.9%) including 2 tibial fractures (0,75%) and 1 non-union (0.37%). Five complications (1.9%) were defined as minor. Removal of the screws because of irritation or pain was seen in 22 cases (8.2%).

Conclusion
A V-shaped TTO is a safe procedure in comparison to other surgical techniques. The presumed higher risk for tibial fractures or pseudo-arthrosis could not be confirmed.

Key terms
MPFL, patellafemoral instability, tibial tubercle, TTO

Introduction

Patellofemoral instability is a common problem in adolescents. In case of recurrent patellar instability, surgical management results in a lower risk of recurrent dislocation than conservative management [1]. Tibial tubercle osteotomy (TTO) is indicated in patients with recurrent patellar dislocations due to patella alta or an increased tibial tubercle trochlear groove (TT-TG) distance. Several types of osteotomies are described: the modified Elmslie-Trillat medialisation technique [2], the Fulkerson anteromedialisation technique [3], a sliding tibial tubercle osteotomy [4] and techniques in which the tibial tuberosity is completely detached [5]. A systematic review by Payne et al. concluded that the risk of complications is related to the employed technique [6]. In his review the complication rate lies between 3.3 and 10.7%. When performing a V-shaped TTO, the tibial tubercle with periosteum is completely detached from the tibia and a step cut osteotomy is used [7]. Some authors suggest that maintaining the medial and/or distal periosteum at the tubercle when performing an osteotomy is crucial for preserving the vascularization and osteotomy union [8, 9]. Also, the fear of causing a tibial stress fracture when using a step-cut osteotomy lives among surgeons [10]. Payne et al. stated that osteotomies that involve complete detachment of the tubercle have an increased risk of non-union and tibial fractures compared with those in which a distal cortical hinge is maintained [6].

However, the hypothesized advantages of the V-shaped TTO are that the risk on non-union is low due to the triangular shape of the bone block with a twice as big bone contact area of trabecular bone and the intrinsically stable nature of the shape of the osteotomy in comparison to a sliding flat osteotomy. Only small sample size studies have been performed on this subject to our knowledge [5, 11]. Large studies reporting complication rates of a V-shaped tibial tubercle osteotomy are missing, but necessary to give a clearer view on this and can help determine the optimal technique. The aim of this study was to report complication rates directly related to the surgical technique of a V-shaped TTO, where the tubercle is completely released from its periosteum using a step-cut osteotomy.

Material and methods

Data collection

All patients operated between March 2004 and October 2017 in the Radboud University Medical Centre, Nijmegen, using a V-shaped tibial tubercle osteotomy (TTO) were included. The indication for a tibial tubercle transfer was recurrent patellar dislocations in combination with a patella alta (Caton-Deschamps index >1.2), as underlying anatomical risk factor after failure of conservative management with or without an increased TT-TG distance. Two experienced surgeons using a similar surgical technique performed all procedures. Additional simultaneous procedures were performed if indicated such as a medial patellofemoral ligament

(MPFL) reconstruction, lateral release, vastus medialis obliquus (VMO) plasty or a trochlear osteotomy. Patient charts were reviewed for data collection. Follow-up was obtained at 6 weeks and 4 months postoperatively in case of fusion without further complications. Longer follow-up was only on indication.

Surgical technique

The tibial tubercle transfer was performed making a V-shaped osteotomy of the attachment of the patellar tendon on the tibial tubercle using a saw and osteotome (Fig. 1A), as earlier described by Caton and Van de Groes [7, 12].

Through an anteromedial approach, the patellar tendon is identified and the periosteum is released. The tibial tubercle is completely detached on three sides with an oscillating saw and osteotome to be able to perform a distal transfer.

A piece of bone from the tibia is removed in order to correct the Caton–Deschamps index to 1 as planned preoperatively. This bone block was placed in the gap on the proximal side to enhance stability and to provide a more stable situation of the tuberosity (Fig. 1B). The osteotomy was fixed using two small fragment lag screws. The screws were countersunk and not placed in the same line to prevent breakage of the tubercle and irritation of the screw heads. Stable compression was obtained.

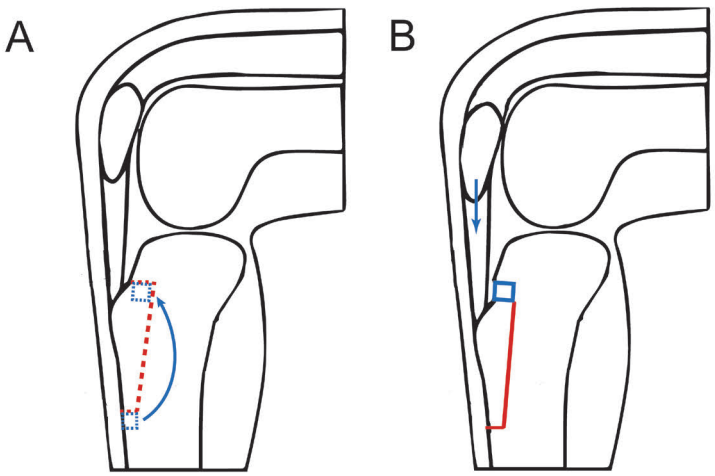


Figure 1. Schematic drawing of the V-shaped tibial tubercle osteotomy for transfer, A: the red dashed line reflects the cut for complete detaching the tibial tubercle. The blue dashed line marks the small bone block that is transferred from distal to proximal. B: situation after distalisation of the tubercle with the bone part from distal put back proximally.

Aftercare

Post-operative care consisted of a removable long leg plaster cast with the knee in full extension for six weeks in the period until 2014. From 2014 to the present no cast is used. Only partial weight bearing was allowed in this period, and a maximal flexion of 70 degrees. If there were no complications after six weeks, full weight bearing and full range of motion was allowed.

Data analysis

Complications related to the surgical procedure were classified as minor or major, according to the criteria used in Payne's review article. [9] Major complications were defined as tibial fractures, non-union, neurovascular complications, infection and wound complications that required surgical intervention. Minor complications include events that are unlikely to have influenced the functional outcome or caused no permanent harm to the patient.

Statistical analysis

Descriptive statistics were used to analyse the frequency of complications as a percentage of total. A Chi –square test was performed to look at differences in male to female ratio, and an unpaired T-test to look at differences in age between the group with and the group without complications

Theory/calculation

This retrospective study quantifies the risk of procedure specific postoperative complications in a large group of patients related to a tibial tubercle transfer using a V-shaped osteotomy performed in a single institution.

Results

Two hundred and sixty-three (263) knees in two hundred and three (203) patients were included. Descriptive statistics are displayed in table 1. The median age at operation was 19 years (range 12 - 49 years). Most patients were female (73.8%).

Median follow-up was 4 months (range 3 - 120 months) because standard follow-up was only up to 4 months if uncomplicated. Most frequent reasons for longer follow-up were: recurrent dislocations, postoperative complications, consultation for contralateral knee issues and request for TTO hardware removal.

An overview of which specific additional procedures performed can be found in table 1. Out of the 263 knees, 144 (54.8%) had at least one additional procedure to the TTO. There was no significant difference in age between patients with and without complications (p= 0.80), but the amount of women in the group with complications was higher compared to the group without complications. (Chi-square 4.5765, p = 0.03).

Patient characteristics	
Number of patients	203
Number of knees	263
Mean age (range)	20.5 (12-49)
	N patients (%)
Female	194 (74)
Additional procedures performed	
None	123 (46)
VMO plasty	51 (19)
Trochlear osteotomy	50 (19)
Lateral release	16 (6)
MPFL reconstruction	7 (3)
Combined	80 (30)

Table 1. Descriptive statistics

Major complications

Thirteen knees (4.9%) had a major complication. An overview of complications is displayed in table 2. Two patients (0.76%) sustained a tibial shaft fracture at the side of the step cut performed during the transfer surgery. The first patient while jumping on one leg during rehabilitation 2.5 months after surgery, the other after 6.5 months after a fall. Both fractures were stabilized with a locking compression plate. There were two cases in which there was a problem with the part of bone removed from the distal side that was pressed into the proximal part of the osteotomy. In one patient the bone block became a loose body that was removed arthroscopically. In the second case this bone block was malpositioned directly underneath the patellar tendon and caused tendinopathy, and was surgically removed. There was one case of septic arthritis (0.38%) and one with a non-union (0.38%). The patient with a non-union was re-operated after 9 months. A fibrous layer on the V-shaped fragment was excised and a third screw was placed to increase stability, this resulted in consolidation after 5 months. Proximalisation of the tubercle without screw breakage was seen in three patients (1.14%), this was recognized after 10 days, 3 weeks and 3 months; all three patients had the screws revised after which the osteotomy fully consolidated. In one patient the malunion was seen after 4 years after a recurrent patellar dislocation. The bone was healed, but during the growth the screws were pulled oblique so the tubercle proximalised again. A correction TTO was performed. Screw breakage occurred only once, discovered 6 months after surgery but with consolidation of the osteotomy and a Caton index of 1.1 so no further action was needed. In one case the tibial tubercle fractured three days after surgery because of an epileptic insult with maximum quadriceps contraction so it was fixated with a small buttress plate.

Minor complications

In five knees (1.9%) minor complications occurred (table 2). Two patients (0.76%) had a thromboembolic event. The other three complications occurred only once (0.38%): a superficial wound infection with a S. Aureus for which this patient got antibiotics for 6 weeks, a deep flexion contracture of 90 degrees which restored without further surgery after 5 months to 130 degrees and a delayed union. This last patient had to wear an extension brace with restricted flexion without resistance up to 60 degrees until 5 months postoperatively, after which the osteotomy consolidated. No cases of persisting disability in range of motion were seen.

Hardware removal

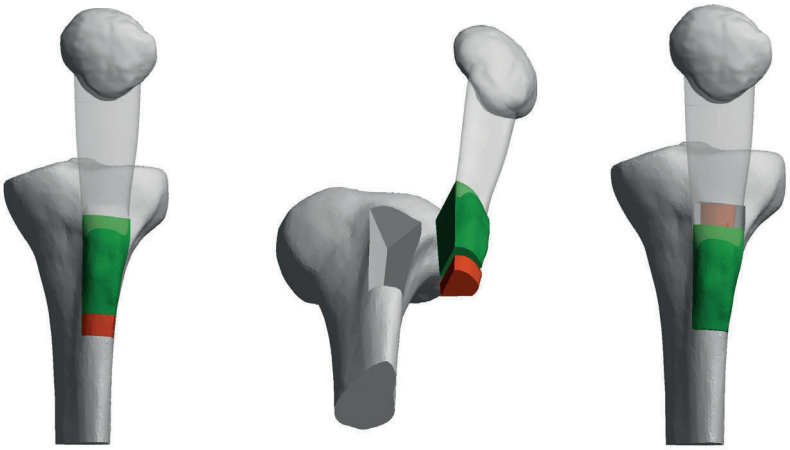
Twenty-two knees had the screws removed because of pain or irritation (8.4%).

Results	**N (%)**
Major complication	**13 (4.9)**
Fracture	3
Tibial shaft	2
Tibial tubercle	1
Non- or malunion	6
Delayed union	4
Non-union	1
Malunion	1
Malposition bone block	2
Septic arthritis	1
Minor complication	**5 (1.9)**
Thromboembolic event	2
Wound infection	1
Delayed union	1
Delayed FROM	1

Table 2. Occurrence and demographics of complications TTO

Discussion

The major findings of this study are the low incidence of non-union and tibial fractures. Kanamiya et al suggest that when a complete detachment of the tibial tubercle is performed and the medial, lateral and distal periosteum is transected, this leads to a complete arrest of the blood flow and a higher chance of non-union [8]. From our data we cannot confirm this theoretical concept in practice. Compared to the non-union rate of 0.8% in 787 TTO's published by Payne et al. [6] in their systematic review, the incidence in our group (0.38%) is even lower. This could be due to the bigger contact area of the V-shaped osteotomy with more trabecular bone for better bone healing (figure 2).



a. b. c.

Figure 2. Three-dimensional schematic imaging of the TTO technique before (a), during (b), and after (c) the V-shaped osteotomy.

Secondly, tibial fractures were only seen in 0.76%, again less than reported by Payne et al. [6] (2.4% when using a detached TTO) or Luhmann et al. [10].

There were no early tibial fractures. After the second tibial fracture, the aftercare was changed where instead of 50% only 10% of weight bearing was allowed for six weeks. Although both tibial fracture were seen after this first six weeks, we think that protecting the tibia in the first stadium of bone healing will give less excessive stress on the damaged cortex at the distal cut, which is perpendicular to the shaft, and so prevents tibial shaft fractures. In both cases, the piece of bone that was resected was not placed back proximally because it did not fit. This might have caused a lack of stability, which could be the reason the tibial shaft broke. Secondly, it is very important to make the distal cut carefully and not too far into the cortex of the tibia. If this happens, this will be the weak spot for stress rising.

In three cases the tibial tubercle proximalized without breakage of the screws. It has been recommended that these screws should be at least 2 mm longer than the measured bi-cortical distance to ensure adequate bite [13]. In retrospect this was not the case in two out of three situations.

In only one case the piece of bone that was trans positioned from distal to proximal became loose. So no additional fixation is necessary for this bone block besides compression between the cortices.

The infection rate (0.76%) was with once a septic arthritis and one superficial wound infection comparable to the findings of Payne et al. [6].

The other remarkable finding was the low number of screw removal in this case series. Most studies maintain percentages up to 50% of hardware removal in TTO. Payne found that in the complete tubercle detachment group this risk was 48.3%. One of the reasons why in this study this percentage is only as low as 8.4% is that we use the countersink when placing the screws. Secondly, all patients got instructed that the hardware is only removed in case of specific complaints of the screws.

The most important weakness is the retrospective nature of this study, using only available patient charts. Because the highly specialized character of our clinical practice in patellofemoral instability, the chances that complications occurred without our knowledge are small. All patients were followed up until at least 4 months, so wound problems or non-unions would have been detected. It is very unlikely that tibial fractures were treated in another clinic. A distinct advantage of this study is its large sample size and the uniform technique that was used.

Conclusion

A V-shaped tibial tubercle osteotomy is a (relatively) safe procedure with a low complication rate. The risks on non-union and tibial fractures are particularly low, despite complete detachment of the periosteum and using a step cut osteotomy.

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CHAPTER 5

AGE AT SURGERY IS CORRELATED WITH PAIN SCORES FOLLOWING TROCHLEAR OSTEOTOMY IN LATERAL PATELLAR INSTABILITY; A CROSS-SECTIONAL STUDY OF 113 CASES

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Abstract

Background
A trochlear osteotomy aims to restore patellar stability in patients with recurrent patellar instability and trochlear dysplasia. The age of patients at time of surgery could be a relevant factor which influences outcome. We hypothesized that lower age at time of surgery is associated with better patient reported outcomes.

Methods
A retrospective study was conducted on patients with patellar instability and trochlear dysplasia. Patients were contacted by phone for informed consent and were then asked to complete online patient reported outcome measurements (PROMs) . The PROMs consisted of the Kujala Knee Score (KKS) [1, 2], the Short Form 36-item health survey (SF-36v1)[3, 4] and visual analogue scale (VAS) scoring pain, instability, disability and satisfaction on a 0-100 scale. Multivariable linear regression models were used to study the effect of age on the PROM scores.

Results
For this study 125 surgical procedures in 113 patients were included. Mean VAS pain at rest was 19 and at activity 38, mean Kujala score was 73. Multivariable regression analysis revealed that age at time of surgery was correlated with VAS pain at rest, with a 0.95 increase of VAS score (scale 0-100) for every year of age. Recurrence of instability was observed in 13 (10%) knees.

Conclusion
In this cross-sectional study, pain scores of 113 patients who have undergone a lateral facet elevating trochlear osteotomy for patellar instability were reported. Age at time of surgery was correlated with an increased pain score at rest with an average of 9.5 points (scale 0-100) for every 10 years of age. Age at time of surgery was not correlated with overall satisfaction.

Key words
Patella, Patellofemoral joint, Patellar instability, trochlear dysplasia, trochlear osteotomy

Background

Patellar instability is a common problem seen by orthopedic surgeons. The annual incidence of primary patellar dislocation has been estimated at 43 per 100,000 in children under 16 years [5]. Recurrent patellar dislocation occurs in 15% to 45% of primary dislocation cases [6-11]. Patellofemoral stability is maintained by static stabilization of bony and soft tissue structures on the one hand and by dynamic stabilization through the activation of muscles on the other hand. The lateral displacement is statically restrained by the lateral facet of the trochlea and the medial patellofemoral ligament (MPFL) and mechanical alignment. Dynamic stabilization occurs by the activation and relaxation of co-acting muscles and muscle groups that directly or indirectly influence the position of the patella relative to the trochlea. Trochlear dysplasia is a condition in which the development of the trochlea results in an abnormal geometry, with a shallow, flat or a convex shape of the sulcus. It has been identified as the most consistent anatomic factor present in patients with recurrent patellar dislocations [12]. For the surgical treatment of patients with recurrent patellar dislocations and trochlear dysplasia, various surgical procedures have been described to reshape the abnormal trochlea [13, 14]. Trochlear osteotomies directly modify the patellofemoral joint with the risk of causing cartilage damage and alteration of joint kinematics and contact pressures[14]. Normal joint kinematics and contact pressures are fundamental for the long-term joint preservation and abnormalities in these factors could potentially lead to development of early patellofemoral osteoarthritis [13-16]. Due to the presumed susceptibility of complications of a trochlear osteotomy, these procedures are not performed often. However, a systematic review of literature demonstrated that the rate of major complications is comparable to those of other patellar stabilizing procedures [17].

The indication for trochlear osteotomies is still a matter of debate. Combination of the procedure with another bony or soft tissue procedure is often necessary to achieve patellar stability throughout the full range of knee motion. Patellar stability is reported to be restored in a large majority of patients who had a trochlear osteotomy [13, 18, 19].

Next to the anatomical abnormalities such as trochlear dysplasia, patella alta and insufficiency of the MPFL, other patient factors such as their age could be of influence on the results of surgery for patellar instability. Multiple studies have shown that a correlation exists between the age of patients and the risk on recurrent dislocation and the outcomes of surgery. A study of Fithian et al. indicated that patients with initial injury at a younger age had a higher risk of subsequent patellar subluxation or dislocation [11]. Hiemstra et al. found a correlation between age at time of surgery (MPFL-reconstruction) and outcome[20]. Palmu et al.[21] reported a redislocation rate of 67% following operative treatment for acute patellar dislocation in children younger than sixteen years of age, which is much higher than the pooled risk of redislocation of 12% presented by Smith

et al.[22] in their systematic review. Age at time of surgery might therefore be a factor for the risk of redislocation and patient reported outcome of surgery. In addition to these correlations, adolescent patients are expected to have more pliable osseocartilaginous structures than the older patients [23], this might lead to less cartilage damage by focal aseptic necrosis, better malleability and therefore better clinical results in patients of a younger age.

The main goal of this study was to evaluate the effect of age on patient reported outcome after a lateral facet elevating trochlear osteotomy in a large cohort.

We hypothesized that lower age at time of surgery is associated with better patient reported outcomes.

Methods

Patients

Data for this study was collected retrospectively. Patients who have undergone a lateral facet elevating trochlear osteotomy to restore patellar stability in Radboudumc, Nijmegen between 2005 and 2015 were included in this study. All operations were carried out by one senior orthopedic surgeon (AK) using the same surgical technique over time (described below). Indications for trochlear osteotomy were recurrent patellar dislocation or subluxation in the presence of a positive J-sign and radiographically confirmed trochlear dysplasia on a true lateral X-ray according to the criteria of Dejour [24]. Radiologically closed epiphyses stage 3 or 4 (scale range 0-4) was confirmed in all patients, this was scaled according to the method described by O'Connor et al.[25]. Stage 3 indicates recent union, stage 4 indicates complete union when remodeling has taken place and there is continuity of trabeculae form shaft to former epiphysis.

This study was approved by the Medical Ethical Review Board of the Radboudumc, Nijmegen, The Netherlands (CMO 2015-1943).

Methods of assessment

The research team contacted each participant by phone to explain the study and have the participants complete patients reported outcome measurements (PROMs). A secured website was used to complete reports. The PROMs included the Kujala Knee Score (KKS) [1, 2], the Short Form 36-item health survey (SF-36v1)[3, 4] and visual analogue scale (VAS) scoring pain, instability, disability and satisfaction. At time of surgery, no pre-operative or post-operative PROMs were collected. Due to the retrospective nature of this study, those data are lacking and are not included in the analysis.

Statistical analysis

Descriptive statistics were used to summarize the data. Multivariable linear regression models were used to evaluate the association between age (independent variable) and VAS and KKS scores (dependent variables). Based on clinical experience and published literature we selected gender, history of surgery, presence of low or high grade trochlear dysplasia (low vs. high grade: A or C vs. B or D), postoperative patellar height, BMI and whether or not additional procedures were performed as independent variables that could influence patient reported outcome of surgery [26-28]. The multivariable regression analysis adjusts for these factors. Due to a lack of data, BMI as independent variable was not taken into account for analysis. A P-value of <0.05 was considered statistically significant. All statistical analysis were performed using SPSS (v20, IBM SPSS Statistics, Armonk, NY, USA).

Surgical technique

A surgical technique was used as previously described by Koëter et al. [29] and slightly differs from the lateral facet elevating trochlear osteotomy as described by Albee and Weiker [30, 31]. In brief, the patient was placed supine on the table. Antibiotics were admitted preoperatively. No tourniquet was used. A lateral parapatellar incision was made and extended distally along the lateral femoral condyle. The retinaculum was opened in the direction of the femur. To visualize the osteotomy, two Kirschner wires were placed in the direction of the osteotomy till they were visible through the cartilage (halfway between the medial and lateral femoral facet). With the use of a small osteotome, an incomplete lateral trochlear osteotomy was carried out (figure 1). The curved osteotomy extended from the beginning of the trochlea proximally to the sulcus terminalis distally. Subsequently, the lateral articular surface of the trochlea was levered. In most cases, it was possible to raise the lateral articular surface by 4-6 millimeters. A wedge-shaped autograft was created with a part of the ipsilateral iliac crest to secure the elevation of the osteotomy; this graft was changed to a tricalcium phosphate (TCP) wedge during the study period (figure 2). Fixation of the osteotomy with osteosynthesis material was not needed. After performance of the osteotomy, the synovium was closed over while the lateral retinaculum was left open. Postoperatively, patients were placed on a continuous passive motion device (CPM) to stimulate a full passive range of motion until knee flexion was at least 60°. Patients were recommended the following training schedule: partial weight bearing for the first six weeks, without flexion limitation. After six weeks, full weight bearing was allowed. Patients were only referred to a physical therapist if restorage of normal gait was needed.

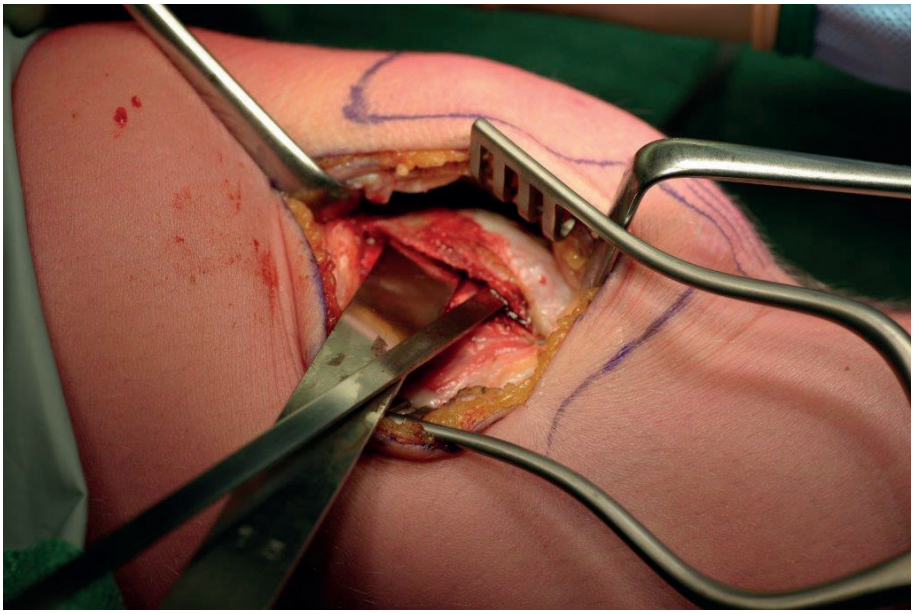

Figure 1. The osteotomy is performed with osteotomes, the proximal is further advanced medially than the distal osteotome.

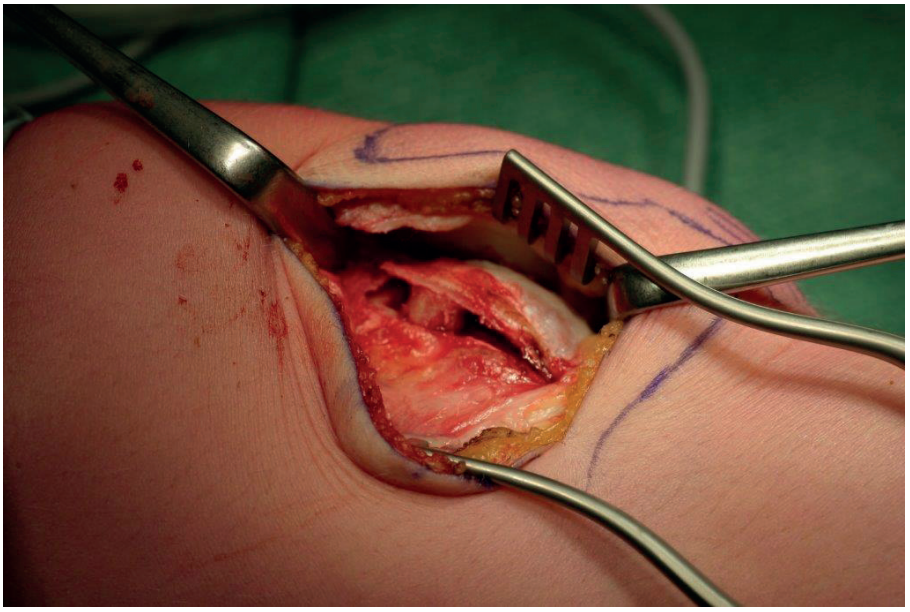

Figure 2. A triangular bone graft or tricalcium phosphate wedge is used to hold the achieved correction.

Results

The patient database of our hospital identified 180 trochlear osteotomies in 150 unique patients, of whom 37 patients (55 procedures) could not be contacted or refused to participate. This led to the inclusion of 113 patients with 125 surgical procedures. Twelve patients had undergone bilateral trochlear osteotomy. Demographics and mean outcome scores are displayed in Table 1. Nine patients had no true lateral X-ray available in the database and were therefore not retrospectively classified into one of the four types of trochlear dysplasia.

Variable	Outcome
Age at surgery in years (range)	19.8 (12.5-46.3)
Follow-up time (months)	71 (12-125)
Gender:	
Female (%)	102 (82)
Type of trochlear dysplasia (%)	
Type A	14 (12)
Type B	55 (49)
Type C	9 (8)
Type D	33 (29)
Previous procedures (%)	16 (13)
Additional procedures (%)	69 (55)
MPFL reconstruction	7 (5.6)
Tibial tuberosity transfer	63 (50)
Complications during follow-up (%)	9 (7)
Flexion deficit	4 (3)
Persisting instability	1 (1)
Removal TCP-wedge	2 (2)
Break-out of osteotomy	1 (1)
Venous thrombo-embolic event	1 (1)
Outcome score	
VAS pain at rest	19 (0-80)
VAS pain at activity	38 (0-90)
VAS instability	40 (0-100)
VAS disability	34 (0-100)
VAS satisfaction	66 (1-100)
Kujala Knee Score	73 (17-100)
SF-36 General health	72 (10-100)

Table 1. Demographic characteristics and outcome scores.

Values represent mean with range, unless otherwise indicated. N is number of knees unless otherwise indicated.

The mean VAS for pain at rest was 19 while this was 38 during activity. The mean VAS for overall satisfaction was 66. The mean KKS was 73 and the mean SF-36 general health perception was 72 (table 1). In our cohort of patients with a mean age of 19.8 years (range 12.5-46.3) at surgery, multivariable regression analysis (Table 2-7) revealed a correlation between age at time of surgery and VAS pain at rest. The VAS pain score at rest increased with 0.95 (0-100 scale) with every year of age at time of surgery (P 0.025). Recurrence of instability was seen in 13 (10%) knees.

Risk factor (independent variable)	Multivariable regression coefficient (95% CI)	P-value
Age at time of surgery	**0.95 (0.12;1.8)**	**0.025**
Female	**12.7 (1.1;24.3)**	**0.032**
Previous procedures performed	10.3 (-3.9;24.5)	0.15
Patellar height	0.12 (-23.0;23.2)	0.99
Trochlear dysplasia A or C vs. B or D	-2.5 (-13.8;8.8)	0.66
Additional MPFL reconstruction	-2.8 (-24.7;19.1)	0.80
Additional tibial tubercle transfer	-0.52 (-10.0;9.0)	0.91

Table 2. Results of multivariable regression analysis for VAS pain rest as dependent variable. CI: confidence interval. Bold risk factor: statistically significant.

Risk factor (independent variable)	Multivariable regression coefficient (95% CI)	P-value
Age at time of surgery	-0.47 (-1,0;0.17)	0.15
Female	**-11.6 (-20.4; -2.7)**	**0.011**
Previous procedures performed	**-16.2 (-27.1; -5.3)**	**0.004**
Patellar height	-11.6 (-29.2;6.1)	0.20
Trochlear dysplasia A or C vs. B or D	2.6 (-6.1;11.3)	0.55
Additional MPFL reconstruction	5.8 (-11.0;22.6)	0.49
Additional tibial tubercle transfer	0.94 (-6.3;8.2)	0.80

Table 3. Results of multivariable regression analysis for Kujala Knee Score as dependent variable. CI: confidence interval. Bold risk factor: statistically significant.

Risk factor (independent variable)	Multivariable regression coefficient (95% CI)	P-value
Age at time of surgery	0.79 (-0.23;1.8)	0.13
Female	**21.0 (6.8;23.3)**	**0.004**
Previous procedures performed	14.8 (-2.7;32.2)	0.096
Patellar height	9.9 (-18.5;38.3)	0.49
Trochlear dysplasia A or C vs. B or D	-8.0 (-21.9;6.0)	0.26
Additional MPFL reconstruction	1.8 (-25.1;28.8)	0.89
Additional tibial tubercle transfer	-4.4 (-16.0;7.4)	0.46

Table 4. Results of multivariable regression analysis for VAS pain activity as dependent variable. CI: confidence interval. Bold risk factor: statistically significant.

Risk factor (independent variable)	Multivariable regression coefficient (95% CI)	P-value
Age at time of surgery	-0.22 (-1.4;0.96)	0.71
Female	**17.2 (0.58;33.8)**	**0.043**
Previous procedures performed	7.6 (-12.7;27.8)	0.46
Patellar height	19.4 (-13.6;52.4)	0.25
Trochlear dysplasia A or C vs. B or D	4.9 (-11.3;21.2)	0.55
Additional MPFL reconstruction	-1.5 (-32.9;29.8)	0.92
Additional tibial tubercle transfer	1.4 (-12.2;15.0)	0.84

Table 5. Results of multivariable regression analysis for VAS instability as dependent variable. CI: confidence interval. Bold risk factor: statistically significant.

Risk factor (independent variable)	Multivariable regression coefficient (95% CI)	P-value
Age at time of surgery	0.13 (-1.0;1.3)	0.82
Female	8.6 (-7.4;24.6)	0.29
Previous procedures performed	17.1 (-2.5;36.7)	0.086
Patellar height	10.6 (-21.2;42.4)	0.51
Trochlear dysplasia A or C vs. B or D	10.5 (-5.2;26.1)	0.19
Additional MPFL reconstruction	-12.7 (-42.9;17.5)	0.41
Additional tibial tubercle transfer	2.1 (-11.1;15.2)	0.76

Table 6. Results of multivariable regression analysis for VAS disability as dependent variable. CI: confidence interval. Bold risk factor: statistically significant.

Risk factor (independent variable)	Multivariable regression coefficient (95% CI)	P-value
Age at time of surgery	-0.25 (-1.5;1.0)	0.70
Female	**-22.6 (-40.2; -4.9)**	**0.013**
Previous procedures performed	-11.6 (-33.2;10.0)	0.29
Patellar height	-7.5 (-42.7;27.6)	0.67
Trochlear dysplasia A or C vs. B or D	2.8 (-14.5;20.1)	0.75
Additional MPFL reconstruction	5.3 (-28.0;38.7)	0.75
Additional tibial tubercle transfer	-2.2 (-16.7;12.3)	0.76

Table 7. Results of multivariable regression analysis for VAS satisfaction as dependent variable. CI: confidence interval. Bold risk factor: statistically significant.

Complications included a postoperative flexion deficit in four knees. In one knee of a female patient at the age of 47 years at time of surgery, postoperatively the trochlear osteotomy broke out to the distal femoral condyle, open reduction and refixation with two screws was performed, however it resulted in arthrofibrosis and patellofemoral osteoarthritis (PF OA). One patient had persisting instability together with PF OA in the knee and underwent a patellofemoral arthroplasty one year postoperatively, in two patients the tricalciumphospate (TCP) wedge was removed because of dislocation, in one patient it dislocated and in one patient this wedge broke, and one patient had deep venous thrombosis.

Discussion

In this study, we showed that a VAS pain score increased with higher age after a lateral facet elevating trochlear osteotomy. Although the increase is relatively small for every year of age (0.95), it is a clinically relevant increase for every ten years of age (9.5).

This study was not designed to investigate the underlying cause of increased pain, however, the following hypothesis could well be true. Older patients have a longer history of patellofemoral instability (peak incidence of first dislocation is in adolescence [11]). They might have a history of patellar dislocations with a longer period of maltracking of the patella. As a consequence, increased cartilage damage and degenerative changes of the patellofemoral joint would be present at time of surgery. This might have an influence on the level of correction that is possible, the congruency of the new trochlea, the presence of microtears during surgery and the load bearing capacity of the cartilage. These factors could also be influenced by the pliability of the articular cartilage, which decreases with increasing age due to molecular changes. Despite the fact that increasing age is correlated with a higher VAS pain score at rest in our study, we don't assume that this is caused by early PF OA. Although the present study didn't evaluate the radiological presence of PF OA , a study by Tigchelaar et al. [32] showed no clear correlation between VAS pain and the grade of PF OA after trochlear osteotomy. They analyzed data from patients with 12 years of follow-up. Radiological PF OA after surgery was generally limited to lower grades on the Iwano scale [32]. In our study, two older patients (age at surgery 27 and 46 years) had radiologically confirmed PF OA during follow-up; this was radiologically examined because of the presence of persisting pain. Both patients scored high on VAS pain at rest and therefore contributed to an overall increased average in our study. Early symptomatic PF AO is not expected to be the main reason for an increase in mean VAS score at higher age. We hypothesize that decreased adaptation of the cartilage to the new situation results in increased subchondral pressure and higher pain scores at rest.

Age at time of surgery did not have a significant effect on other outcome measurements. However, it should be noticed that a relatively high rate of redislocation after trochlear osteotomy (10%) was found. Age of these patients ranged between 12-22 years with an average of 16 years and is lower than the average age of patients in our cohort (19.8 years). Furthermore, results of the multivariate linear regression analysis revealed significantly higher VAS instability score in females vs. males. With the exception of gender, no other risk factors were significantly correlated with VAS instability. In our cohort, an additional MPFL-reconstruction was only performed in 5.6% of patients. Recently published literature and new surgical techniques for MPFL reconstruction have narrowed the indication for an isolated trochlear osteotomy without MPFL-reconstruction. An additional MPFL-reconstruction probably decreases the rate of redislocation. With

this in mind, a redislocation rate of 10% can be seen as proof of the effectiveness of a trochlear osteotomy in terms of stability.

The mean KKS in our study was 73, this is an acceptable score in our opinion. The systematic review of Balcarek et al. demonstrates higher KKS-scores after trochleoplasty procedures (range 81-92)[33]. However, due to the inclusion- and exclusion criteria (for example the exclusion of studies in which treatment included additional procedures) of their review, it´s difficult to compare our cohort with the studies they have included.

Loss in range of motion occurred in four patients (2%), which was lower in our study than in previously published reports [17]. The standard use of a CPM might have contributed to this. Four patients had a complication related to the TCP-wedge.

The results of our study, including a relatively high rate of patellar redislocation and KKS of 73, emphasizes that patient selection and strict indication for this type of trochleoplasty is highly important for a better outcome. A recent consensus statement from the AOSSM/PFF Patellofemoral Instability Workshop stated that trochleoplasty is rarely indicated in patients with patellar instability [34]. In determining whether surgery for recurrent patellar instability is warranted, trochlear morphology, patellar height, lateralization of the tibial tubercle, sufficiency of the MPFL, age and gender should be considered. None of the different types of dysplasia according to the Dejour were correlated with outcome measurements of this study. The indications for a lateral facet elevating trochlear osteotomy have decreased in recent years. However, we think that there is still a place for this type of trochlear osteotomy in patients with recurrent patellar dislocation with a J-sign at physical exam, underlying trochlear dysplasia without a trochlear bump but with a convex proximal trochlea. In these cases, outcomes are most predictable and the risk of serious complications is low.

This is the first study to investigate the effect of age on the postoperative outcomes of a lateral facet elevating trochlear osteotomy. The strength of this study is the large patient cohort and the use of PROMs which reflect the outcome as experienced by patients and not based on radiographs assessed by clinicians. Despite the minimal number of indications, we are convinced that it´s important to present the outcomes of this type of trochlear osteotomy, studied in a large cohort, in the perspective of personalized treatment for the individual patient.

Our study has also some potential limitations. First, our study population was heterogenic (e.g. different types of dysplasia, multiple additional procedures, etc.). Although intrinsic heterogeneity in patient characteristics and treatment strategy exists in this study, we think that this population reflects the patients seen during daily practice. Second, patients were not physically examined by a clinician. Our study demonstrates that patient reported outcomes, in conjunction with

surgical complications, are most relevant to determine post-surgical outcome. This warrants the use of PROMs in this patient category. Third, a difference in the level of preoperative chondropathy between younger and older patients could influence postoperative outcome, but a quantifiable report on the preoperative chondral status is lacking in our study. A lot of patients with patellar luxation or subluxation have some amount of patellofemoral chondropathy, this is inherent to the underlying pathology. It has not been demonstrated that pre-operative chondral status is associated with postoperative outcome. However, a surgeon should be aware of the possible interaction of chondral status and outcome of surgery.

Conclusion

In this cross-sectional study, pain scores of 113 patients who have undergone a lateral facet elevating trochlear osteotomy for patellar instability were reported. Age at time of surgery was correlated with an increased pain score at rest with an average of 9.5 points (scale 0-100) for every 10 years of age. Age at time of surgery was not correlated with overall satisfaction.

Declarations

Ethics approval and consent to participate
Institutional review board approval was obtained (CMO 2015-1943). All patients received an information letter and were contacted by telephone for explanation of the study and to obtain verbal informed consent.

Consent for publication
Not applicable

Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

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We have received no funding for this study.

Authors' contributions
JS initiated the study by defining the research question and purpose of the study with help of SG. JS performed data collection and analysis and drafted the manuscript. SG was the first author to review drafts of the manuscript and gave final approval of the version to be submitted. NV, AK and GH were second reviewers of drafts of the article and added important feedback for interpretation of the results and for discussion section. GH performed the statistical analyses.

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CHAPTER 6

A STAND-ALONE LATERAL CONDYLE ELEVATING TROCHLEAR OSTEOTOMY LEADS TO HIGH RESIDUAL INSTABILITY BUT NO EXCESSIVE INCREASE IN PATELLOFEMORAL OSTEOARTHRITIS AT 12-YEAR FOLLOW-UP.

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Abstract

Purpose and Hypothesis
Trochlea osteotomy is a rarely performed procedure, only indicated in selected cases. Due to its nature, it could potentially lead to cartilage damage and subsequent early osteoarthritis. We previously reported satisfactory short term results of a lateral condyle elevating osteotomy and now report the long term effect on the clinical outcomes, patellar stability and radiological osteoarthritis.

Methods
16 patients (19 knees) with patellar instability due to trochlear dysplasia were previously included. An isolated lateral condyle elevating trochlear osteotomy was performed between 1995 and 2002. We re-examined all patients at minimum 12 years follow-up. Three patients were lost to follow up and one patient underwent a patellofemoral arthroplasty three years post-operative due to progressive osteoarthritis. Complete follow-up was therefore available in 12 patients (15 knees). Recurrent instability, VAS-pain, WOMAC, Lysholm and Kujala scores were used as outcome measures. Radiologic osteoarthritis was recorded using the Iwano and the Kellgren-Lawrence classification. A repeated-measures ANOVA was used to test for repeated measures (pre-operative, two years, final follow up) and Spearman's correlation coefficient for relations between osteoarthritis and functional scores.

Results
At final follow up, VAS pain showed a non-significant improvement from 53 to 32 and the mean Kujala score was 76. Lysholm (50 to 72, p=0.021) and WOMAC (74 to 91, p=0.021) scores improved from pre-operative to final follow up. There was no significant difference between clinical scores at two years and at final follow-up. Residual patellar instability was reported in 4 out of 15 knees. Three knees showed no patellofemoral osteoarthritis, 8 knees grade 1 and 4 knees grade 2. No correlation between VAS-pain, Lysholm, WOMAC or Kujala score and osteoarthritis could be identified (Spearman's correlation coefficient, all p-values $\geq$0.365).

Conclusions
A stand-alone lateral condyle elevating trochleoplasty results in significant improvement of most clinical scores but when performed as a stand-alone procedure leads to a high percentage of residual instability . In contrast to general believe, we did not find that the development of patellofemoral osteoarthritis after 12 year follow-up exceeded the findings from other case series of trochleoplasties.

Level of Evidence:
Level IV, case series with no comparison group

Introduction

Patellar instability is associated with a number of predisposing factors [1] with trochlear dysplasia as the largest contributor to prevent the lateral patellar displacement [2, 3]. In patients with persistent patellofemoral instability due to trochlear dysplasia, a trochleoplasty can be an effective way to permanently regain stability [4, 5], especially in cases with high grades trochlear dysplasia or in cases where other procedures have failed [6]. Based on the Dejour classification [7], a trochleoplasty can be indicated in trochlear dysplasia grade B,C and D [6, 8, 9].

The main goal of a trochleoplasty is to restore the lateral bony restraint to normal biomechanical parameters. Due to the nature of this procedure, it could potentially lead to cartilage damage and an increased risk of early osteoarthritis as it changes the congruency of the articulating surface of the distal femur[9]. Multiple techniques and specific procedures have been described [6, 9-12]. Opposed to a sulcus deepening trochleoplasty, a procedure in which the central part of the trochlea is deepened [9], another option is to raise the lateral side of the trochlea through an elevating anterior lateral femoral condyle osteotomy. A primitive version of this technique was described by Albee in 1915 [12]. Although most review articles mention this technique as a reasonable option [8], literature on the results of this technique is limited [13, 14]. The only two previous reports are of poor methodologic quality and included only a few patients. The general perception is that a lateral condyle elevating trochleoplasty will raise patellofemoral contact pressures and therefore initiate patellofemoral pain and cartilage degeneration[9]. The scientific evidence for this presumption is scarce and is only supported by one biomechanical study by Kuroda et al. who found raised pressures when the trochlea was elevated 6 to 10 mm in a cadaver model [15]. We have used this procedure for high grade trochlear dysplasia and in patients with trochlear dysplasia in which other procedures failed. We previously published short term results of this trochlear osteotomy in these difficult to treat patients [16]. We found no residual instability in 17 out of 19 knees and marked improvement in pain and functional scores in most patients at a mean follow-up of 51 months, and concluded that the results were satisfactory.

Purpose and hypothesis

In order to establish the long-term results of this procedure, we now re-evaluated these same patients to investigate the long-term outcomes of this lateral condyle elevating trochlear osteotomy. The aim of this study is to describe the clinical and radiological results of this surgical technique in patients at a minimum of 12 years post-operative with emphasis on (1) the clinical results with regard to functional scores and patellar stability and (2) the occurrence of osteoarthritis. We hypothesized that both the clinical and radiologic results would deteriorate over time.

Patients and Methods

In our previous study we reported on 16 consecutive patients (19 knees)[16]. Inclusion criteria were objective patellar instability due to isolated trochlear dysplasia as established on true lateral conventional radiographs and closed physes. Patients were treated with a stand-alone anterior lateral femoral osteotomy without simultaneous procedures between June 1995 and October 2002 by the senior author (AK) (see: *Operative Technique*). We approached all 16 patients (19 knees) to participate in this study. Two patients were unwilling to participate and 1 patient could not be contacted and was considered lost to follow-up. As already reported in our previous study [16], one patient had a patellofemoral arthroplasty 3 years after her trochlear osteotomy, at age 46 years, due to progressive osteoarthritis. A grade 2 osteoarthritis on the Iwano scale was seen at time of the trochlear osteotomy and a grade 3 when she received the patellofemoral arthroplasty. She underwent a lateral release and medial reefing prior to her trochlear osteotomy. Because of the nature and inherent drawbacks of this procedure we were not able to compare her results (clinical, radiologic and functional scores) with the other patients. Follow-up could therefore be obtained in 12 patients and 15 knees. Fourteen knees were available for physical evaluation as one patient was unwilling to travel to our clinic. She did complete the scores and radiographs were performed elsewhere. The study had ethical approval (Registration number: NL48316.091.14) and all participating patients gave informed consent. Data collection was conducted at a single outpatient visit. Medical history since last follow-up and validated questionnaires were taken: late complications, subsequent surgeries, the number of recurrent dislocations, VAS pain and Lysholm[17] and WOMAC knee scores were recorded. The Kujala [18] score was not previously recorded but noted at final follow up to make our study results more comparable to other studies as all recent reports use the Kujala score.

Physical examination of the knee was performed. In patients who had undergone bilateral surgery, each knee was evaluated separately. The function and stability of the knee were examined with tests for maltracking and instability including the apprehension test and the Rabot and J-signs. Conventional radiographs were taken in an AP, true lateral 19 and 30° patella skyline view. Osteoarthritis was graded using the Kellgren-Lawrence (K-L) scale 20 in the medial and lateral compartments of the tibiofemoral joint and using the Iwano scale 21 for the patellofemoral joint. The mean follow-up was 14.3 years (range 11.9 to 19.0 years). Mean age at follow up was 36.5 years (range 28.9-47.1 years). There were 3 males (4 knees) and 9 females (11 knees). Seven knees had realignment procedures of different kind prior to trochlear osteotomy. These included two Roux-Goldwaith procedures, two tibial tubercle transfers, one medial reefing and lateral release, one combined tibial tubercle transfer and medial reefing and one knee was treated with a medial reefing, lateral release and followed by a varus inducing osteotomy. In one knee only an arthroscopy was performed and 7 knees did not have any previous

surgeries. None of the patients had a previous MPFL-reconstruction as it was not an often performed procedure at that time.

After the trochlear osteotomy, 1 patient had multiple surgeries (including an MPFL-reconstruction), 1 patient had a tibial tubercle distalisation and 1 patient had a tibial tubercle distalisation and medialisation 2 months post-operative (all patients unilateral), because of persistent instability. None of the patients with additional procedures post trochlear osteotomy had persisting instability afterwards. Twelve knees (9 patients) did not have any further surgeries.

Where possible, results were compared to the pre-operative values and the results at 2 years follow-up.

Operative technique [16]

After the skin incision, a lateral parapatellar incision is made and extended distally along the lateral femoral condyle. To visualize the osteotomy, two Kirschner wires are placed in the direction of the osteotomy till they are visible through the cartilage (halfway between the medial and lateral femoral facet). A curved incomplete osteotomy with small osteotomes from the beginning of the trochlea proximally to the subchondral bone of the sulcus terminalis distally is performed. The lateral articular surface of the trochlea is levered 6–8 mm, and the osteotomy is secured with a wedge shaped autograft taken from the ipsilateral iliac crest (Figure 1). Fixation of the osteotomy with osteosynthesis material is not necessary. The synovium is closed over the previously performed osteotomy, the lateral retinaculum is left open (i.e. a lateral release). This was done in order not to over tighten the lateral structures after the lateral condyle was raised. Postoperatively, patients were placed on a continuous passive motion device (CPM) to stimulate a passive range of motion until knee flexion was at least 60 degrees. Patients were advised partial weight bearing without flexion limitation for the first 6 weeks postoperatively.

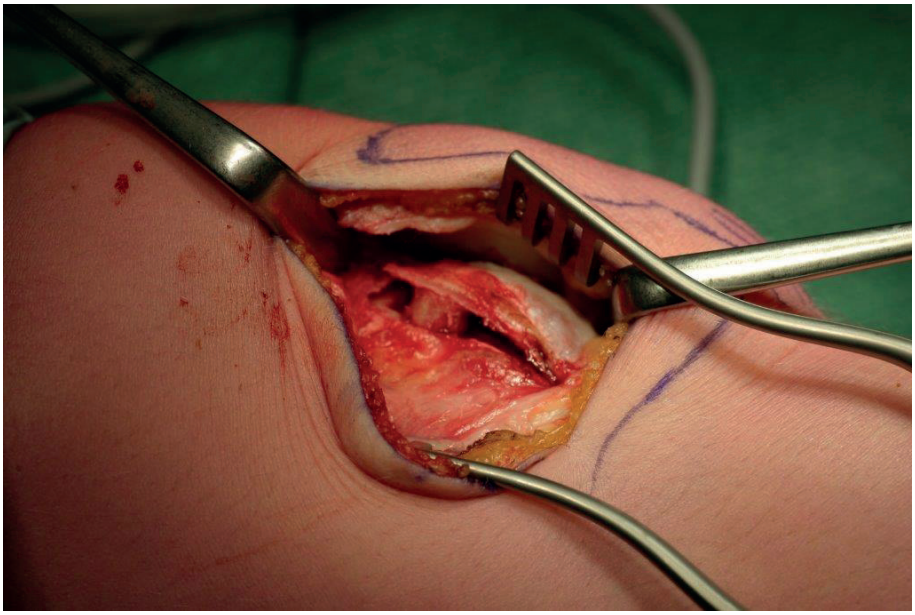

Figure 1. Lateral condyle elevating trochlear osteotomy. The osteotomy extends from the beginning of the trochlea proximal and extends to the sulcus terminalis distal. It is secured by a bonegraft from the iliac crest.

Statistical Analysis

Data analysis was performed with SPSS version 20.0 (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY, US). A repeated-measures ANOVA was used to test for repeated measures (pre-op, two years, final follow up) of VAS pain, Lysholm and WOMAC scores. Correction for multiple comparisons was done using Fisher's least significant difference. Spearman's correlation coefficient

was calculated between the grades of OA of the patellofemoral joint and the medial and lateral tibiofemoral joint and the VAS pain, WOMAC, Kujala and Lysholm scores. For all datasets, differences with P-values < 0.05 were considered statistically significant.

Results

The mean values for VAS-pain, Kujala, Lysholm and WOMAC scores pre-operative, at 2 years and at final follow-up are depicted in Table 1. All scores showed an improvement from pre-operative to 2 years follow up and showed no significant deterioration from 2 years to final follow up.

Post-operative, a subjective feeling of patellar instability was reported continuously or at light exertion in 6 knees (5 patients) out of which objective patellar

dislocations were reported in 4 knees (4 patients)(table 2). This rate of patellar instability is higher than reported at two years follow-up at which time only 2 patellar dislocations had occurred, both within the first months postoperatively. On physical examination, no knees showed swelling or effusion. All knees had a full range of motion. A positive apprehension test for patellar dislocation was present in 3 out of 14 knees, a positive J-sign in 7 out of 14 and the Rabot sign was positive in 12 out of 14 knees (Table 3).

Radiological evaluation of osteoarthritis in the patellofemoral compartment according to the Iwano classification [21] (Figure 2) is shown in Table 4. According to the K-L scale [20], assessment of osteoarthritis in the medial tibiofemoral compartment showed no osteoarthritis in 7 out of 15 knees (46.7%) and grade 1 in 8 out of 15 knees (53.4%) and on the lateral side no osteoarthritis in 7, grade 1 in 7 and grade 2 in 1 out of 15 knees (46.7%, 46.7%, and 6.7% respectively). We observed an increase in radiologic osteoarthritis in all 3 compartments when compared to its pre-operative values, but it is limited to the lower grades on both the Iwano and K-L classifications. In addition to these 15 knees, one patient (one knee) was converted to a patellofemoral arthroplasty due to progressive osteoarthritis and pain 3 years after her trochlear osteotomy. No correlation between VAS-pain, Lysholm, WOMAC or Kujala score and either patellofemoral or tibiofemoral osteoarthritis could be identified (Spearman's correlation coefficient, p-values all $\geq$0.365).

Score	Pre-operative	2-years follow-up	Final follow-up	P-value (figures in bold are significant)
VAS-pain	52.5	23.1	32.3	*** p=0.003**
(range, std dev.)	(7-95, 30.1)	(0-60, 17.7)	(0-66, 28.0)	† p=0.134
				ǂ p=0.271
Lysholm	49.5	80.9	71.8	*** p=0.000**
	(27-78, 17.7)	(54-100, 15.5)	(35-100, 18.6)	**† p=0.021**
				ǂ p=0.050
WOMAC	73.9	89.5	91.2	*** p=0.012**
	(50-100, 20.5)	(65-100, 10.7)	(74-100, 9.1)	**† p=0.021**
				ǂ p=0.618
Kujala	Not performed	Not performed	75.57	Not applicable
			(40-100, 19.0)	

Table 1. Median values for VAS-pain, Kujala, Lysholm and WOMAC scores pre-operative, at 2 years follow-up and at final follow up.

Std. dev.= Standard deviation.

* Pre-operative to 2 years FU, † Pre-operative to final FU, ǂ 2 years FU to final FU (all repeated-measures ANOVA test)

Patellar Stability		n (%)
Catching of the patella	Never	13 (86.7)
	sometimes	1 (6.7)
	Often	1 (6.7)
Symptoms of patellar instability	never	8 (53.3)
	With severe exertion	1 (6.7)
	With light exertion	5 (33.3)
	Continuous	1 (6.7)
Patellar dislocations	None	11 (73,3)
	Once	0 (0)
	2-5 times	1 (6.7)
	Over 5 times	3 (20)
Total		15 (100)

Table 2. The assessment of outcome for patellar instability

Physical exam findings	n/N (%)
Positive Signe du Rabot	12/14 (86)
J-Sign present	7/14 (50)
Positive apprehension test	3/14 (21)

Table 3. Physical examination: patellofemoral evaluation (n=14)

Patellofemoral evaluation in 14 knees, as one knee was not available for physical examination.

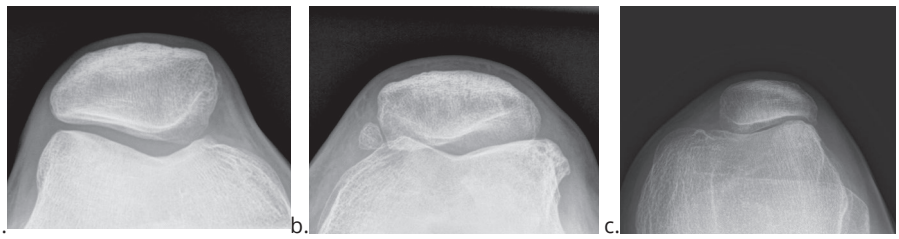

Figure 2. Conventional radiographs of the three grades of patellofemoral OA according to the Iwano classification showing (a) grade 0, no features of OA; (b) grade I, remodeling; (c) grade II, joint space narrowing of < 3 mm.

Location	Classification	Pre-operative	2 year FU	12 year FU
		No of knees (%)	No of knees (%)	No of knees (%)
	Iwano			
Patellofemoral	None	14 (93.3)	13 (86.6)	3 (20)
	Stage 1	1 (6.7)	1 (6.7)	8 (53.3)
	Stage 2	0 (0)	1 (6.7)	4 (26.7)
Total		15 (100%)	15 (100%)	15 (100%)
Note	In addition to these 15 knees, one patient underwent a patellofemoral arthroplasty 3 years post trochlear osteotomy.			

Table 4. Radiological evaluation of patellofemoral and tibiofemoral osteoarthritis.

Discussion

This study shows that the clinical results of this lateral condyle elevating osteotomy do not significantly deteriorate over time. However, a high percentage of patients reported residual patellofemoral instability with objective and subjective symptoms of instability requiring additional surgery. Patellofemoral osteoarthritis was generally confined to the lower grades on the Iwano scale. We conclude that this procedure has acceptable clinical results and does not lead to rapidly progressive osteoarthritis. It can have a place in the arsenal of treatments for patellofemoral instability, but it should not be performed as a stand-alone procedure since it is not sufficient in guaranteeing patellar stability.

This is the largest study on the results of this type of osteotomy, with the longest follow up. We found only two previous studies of poor methodologic quality which reported on the results of this type of osteotomy. In 2003 Badhe et al reported on four patients with a follow up of just one year [13]. They performed a lateral condyle elevating trochleoplasty in combination with an osteotomy of the patella and a tibial tuberosity transfer. They found no instability but all patients had a loss of flexion and residual patellofemoral pain. In 1997 Weiker and Black reviewed five patients (six knees) with an average follow up of 7 years [14]. All patients had a deficient lateral condyle and 3.8 previous surgical procedures on average, including 2 complete patellectomies. They found persistent symptoms in all 6 knees; 4 with sport activities, 1 with activities in daily living, and one knee was eventually converted to an arthrodesis. In 2 out of 4 knees in which radiographic follow up was available, osteophytes were present. When compared to our study these results appear worse both clinically and radiographically.

The VAS-pain, Lysholm and WOMAC scores in our study all showed improvement from pre-operative to final evaluation and the mean Kujala score at final follow up was 76. Most authors describe the results at short- or mid-term follow up. In a recent systemic review by Balcarek et al. [5], results of a sulcus deepening

trochleoplasty were reviewed. They included 6 studies and a total of 186 knees, with and without concomitant stabilizing procedures. The mean follow-up was 44 months and 4 out of 6 studies had a follow up less than three years. The mean postoperative Kujala score ranged from 81.7 to 92.1 and the mean increase in Kujala score was 26.2 points. Few authors published results after a longer follow up[10, 22, 23]. Dejour et al. [23] reported a Kujala score of 81 at a mean follow-up of 66 months and Ntagiopoulos et al. [22] published a Kujala score of 87 at a mean of 7 years follow-up, both after a Dejour type trochleoplasty. Both these studies were also incorporated in the systematic review of Balcarek et al [5]. Von Knoch et al. reported a mean postoperative Kujala score of 95 in 45 knees after a Bereiter trochleoplasty at eight year follow-up [10]. In these series the authors described highly variable results, patellofemoral pain improved in 22 out of 45 knees postoperatively, but worsened in 15 out of 45 knees. Unfortunately we are not able to report a difference in pre- and post-operative Kujala scores as it was not recorded pre-operative, but the mean Kujala scores reported in other studies are higher than in our results.

The reported recurrence of patellar instability in our study (table 3) is higher than reported in other studies. Beaufils et al published an overview of the incidence of recurrent dislocations after trochlear osteotomies 6 and reported a maximum of 10% (2 out of 20 patients) of persistent objective patellar instability in one study by Thaunat et al24 and 2% in two other studies25, 26. No persistent instability was reported in the other six studies4, 10, 11, 27-29 included in their overview. These results are confirmed by Balcarek et al who found recurrent instability in 4 out of 186 knees (2.1%) in their systematic review 5. However, most patients in these studies used additional procedures during the index procedure such as an MPFL-reconstruction, lateral release, medial reefing or tibial tuberosity transfers. In our study, no additional procedures were performed during the index surgery. Additional realignment procedures were performed in 7 out of 15 knees prior to surgery and in 3 knees at a later stage when there was persistent patellar instability. At latest follow up, 6 patients reported symptoms of patellar instability in 7 knees out of which 4 patients reported recurrent patella dislocations in 4 knees (Table 2). Given the results of our study and those mentioned above, we advise not to perform this trochlear osteotomy as a stand-alone procedure but to combine it with a medial soft tissue stabilizing technique such as an MPFL reconstruction.

Pre-operatively, we observed no osteoarthritis in 14 out of 15 knees and at final follow up we observed radiological patellofemoral osteoarthritis Iwano grade 1 or 2 in 12 out of 15 knees21, and one patient underwent a patellofemoral arthroplasty. This is higher than the occurrence of osteoarthritis after conservative treatment for patellar instability, which has been reported to be 29% (6/21) classified by the Ahlbäck scale at 14 years follow up 30. Out of the few studies with a longer follow up, Von Knoch found a similar incidence of degenerative changes in the patellofemoral joint (73%, 24 out of 33 knees) at 8 years follow up after a Bereiter

trochleoplasty 10. On the Iwano scale, they reported a grade 1 in 14 knees, grade 2 in 7, grade 3 in 2 and grade 4 in 1 knee. Ntagiopoulos et al 22 remarkably found no radiological osteoarthritis at all at a mean of 7 years follow up after their sulcus deepening trochleoplasty. In contrast, Rouanet et al found grade 2 or more radiological osteoarthritis on the Iwano scale in 20 out of 34 knees at 15 years follow up in their series of a sulcus deepening trochleoplasty and 7 knees were already converted to a total knee arthroplasty after the same procedure 31.

General perception on the Albee or lateral condyle elevating procedures is that by raising the lateral condyle, pressures in the patellofemoral joint increase and thus would lead to patellofemoral osteoarthritis. This idea is supported by a study by Kuroda et al who found increased contact pressures in a cadaver model after the lateral trochlea was raised [15]. In contrast, other authors have reported that a larger sulcus angle, i.e. a flatter trochlea, especially in the proximal trochlea, leads to increased cartilage loss [32-34]. Raising the lateral condyle, and thus restoring the normal inclination of the lateral wall of the trochlea, would then act to preserve the cartilage of the patellofemoral joint instead of leading to an increase in osteoarthritis. Based on our results and the reported results from other studies, we must conclude that a lateral condyle elevating trochlear osteotomy leads to an increase in patellofemoral osteoarthritis, but it does not exceed the amount of osteoarthritis reported in other types of trochleoplasties.

The major strength of this study is its long term follow-up and thorough evaluation at final follow up with physical examination and radiographs. Due to the nature of this procedure, it is indicated in relatively few cases of patellar instability. In this study only 19 knees were included in the original series of which 15 were available for final follow up. Therefore 4 out of 19 knees (21.1%, including the one patient who could not be evaluated due to the conversion to a patellofemoral arthroplasty) were not available for follow up, diminishing the power of the study. Additionally, no Kujala score was performed pre-operatively, which makes a proper comparison to other studies difficult as not pre- and post-operative difference could be determined.

Conclusion

Based on this study, we must conclude that a single lateral condyle elevating trochlear osteotomy leads to a high amount of residual patellofemoral instability when compared to studies in which trochleoplasty was combined with other realignment procedures. We therefore advice not to use it as a stand-alone procedure but always perform a simultaneous medial patellofemoral ligament reconstruction. After 12 years follow-up we did not find that the development of patellofemoral osteoarthritis exceeded the findings from other case series of trochleoplasties.

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Conflict of interests
The authors declare that they have no competing interests.

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CHAPTER 7

TROCHLEOPLASTY PROCEDURES SHOW COMPLICATION RATES SIMILAR TO OTHER PATELLAR STABILIZING PROCEDURES

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Abstract

Purpose
Trochleoplasty aims to restore patellar stability. Various techniques have been described and almost all authors report successful results. However, the procedure has a significant risk of complications. Purpose of this study was to perform a systematic review and meta-analysis of the available literature to assess the rate of complications after the various techniques used for trochleoplasty procedures.

Materials and methods
MEDLINE, EMBASE, Web of Science and Cochrane Library databases were searched. Studies on patients with recurrent patellar instability treated with a trochleoplasty with or without additional procedure, and reported complications were included. The primary outcome was the rate of complications per technique. A meta-analysis was performed whenever three or more studies per surgical technique could be included.

Results
The selection process resulted in 20 studies included for analysis. A lateral facet elevating trochlear osteotomy was reported by two studies, ten studies reported on a Bereiter trochleoplasty, five on a Dejour trochleoplasty, one on an arthroscopic technique, one on a 'modified' technique and one on a recession wedge trochleoplasty.

Meta-analysis showed that proportion of recurrent dislocation was 0.04 (95%CI 0.02-0.07) for Bereiter trochleoplasty and 0.02 (95%CI 0-0.08) for Dejour trochleoplasty. These proportions were 0.06 (95%CI 0.02-0.13) and 0.09 (95%CI 0.03-0.27) for recurrent instability, 0.07 (95%CI 0.02-0.19) and 0.12 (95%CI 0.00-0.91) for patellofemoral osteoarthritis and 0.08 (95%CI 0.04-0.14) and 0.20 (95%CI 0.11-0.32) for further surgery respectively.

Conclusion
This study demonstrates that the complications after a Bereiter and Dejour trochleoplasty including additional procedures are in the range of those of other patellar stabilizing procedures. For four other techniques, no meta-analysis could be performed. The clinical relevance of this study is that it provides clinicians with the best currently available evidence on the rate of complications after trochleoplasty procedures. This can be helpful in the process of deciding whether or not to perform such a procedure, and can be used to better inform patients about the advantages and disadvantages of different trochleoplasty procedures.

Level of Evidence
Level IV

Key terms

Patellofemoral instability, trochlear dysplasia, trochleoplasty, trochlear osteotomy, complications.

Introduction

Patellar dislocation occurs when the patella completely disengages from the trochlear groove. The most common recurrent symptom after patellar dislocation is patellar instability, which includes both patellar dislocation and subluxation[1]. Trochlear dysplasia has been identified as the most consistent anatomic factor present in patients with recurrent patellar dislocations [2].

Trochleoplasty is a surgical procedure designed to reshape the trochlea in patients with recurrent patellar dislocation and trochlear dysplasia. Trochleoplasty involves working directly on the patellofemoral joint, modifying the congruency between the two articulating bones and alteration of joint kinematics, with a high risk of cartilage damage. The number of trochleoplasty procedures as a primary or revision surgical treatment option in patients with recurrent patellar dislocation and trochlear dysplasia has increased over the last decade [3]. Most authors agree that trochleoplasty procedures should always be combined with soft-tissue and/or with bony procedures (e.g. medial patellofemoral ligament (MPFL) reconstruction (lowest rate of recurrence with double-limb graft configuration [4]), tibial tubercle transposition) as indicated. Therefore, a trochleoplasty procedure could be defined as a trochleoplasty including any additional stabilizing procedure.

Various techniques for trochleoplasty have been described in the past decades. Four basic trochleoplasty procedures can be distinguished: 1) the lateral-facet elevating trochleoplasty as first described by Albee [5], 2) the sulcus-deepening trochleoplasty which was first proposed by Masse [6] and later modified by Dejour[7], 3) the 'Bereiter' or 'thin-flap' procedure[8], and 4) the 'recession' or 'recession-wedge' trochleoplasty [9]. Although, the outcome measures vary widely between individual studies (e.g. Kujala Knee Score, Lysholm Score, Knee Injury and Osteoarthritis Outcome Score etc.), most articles present satisfactory results of trochleoplasty procedures in creating a stable patellofemoral joint in terms of recurrence of patellar dislocation. However, complications are often not included as primary outcome measure but are only briefly described within the results or discussion section in general terms. Patellar redislocation as a complication is rarely reported [3], however postoperative stiffness and return to the operating room for any reason are relatively frequent reported complications.

Trochleoplasty is a highly complex surgical technique with a significant risk for complications [3, 10, 11]. Therefore, it is important to gain more knowledge on complications after trochleoplasty procedures. To assess the rate of complications after the various techniques used for trochleoplasty procedures a systematic review and meta-analysis of the available literature was performed. The results of this study provide clinicians with the best currently available evidence on the rate of complications after a trochleoplasty procedure. This can be helpful to properly inform the patient and to make a well-informed decision as to whether or not to perform this procedure.

Materials and methods

A systematic review was conducted and reported in accordance with the reporting guidance provided in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [12]. The protocol was prospectively registered in PROSPERO(https://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42015029815).

Search

MEDLINE, EMBASE, Web of Science and Cochrane Library databases were searched (last search performed 10 May 2016). The search strategy was determined in collaboration with an information specialist from the medical library of the Radboud University medical center. Keywords used to develop our search strategy were 'patellar instability', 'trochleoplasty', and 'complications'. The detailed search strategy is provided in the Appendix. Reference lists of included studies and relevant reviews were screened for relevant studies. No Grey literature search was undertaken.

Eligibility & Study selection

All articles were screened based on title and abstract by 2 reviewers (JvS, SvdG). In this screening stage, studies were excluded if they fulfilled 1 of the following criteria: 1) no trochleoplasty performed; 2) no clinical outcome study on humans (observational and/or experimental) or description of operative technique; 3) animal study, case report, review article, cadaveric study, in vitro study, biomechanical study or conference proceeding; 4) article not in English, Dutch, French, or German (all languages were screened); 5) article published before 1990. In the subsequent full text screening stage studies were further evaluated for eligibility. Studies were excluded if they met any of criteria 1-5 or 1 of the following: 6) no report of complications; 7) indication for trochleoplasty was not recurrent patellar instability. In addition, studies were excluded if they contained data also published in another included paper. In case of a study being part of a larger, original study, the original study was included. In case of reported preliminary data the most extended paper was included in the analysis. Discrepancies between the reviewers were resolved by discussion and consensus.

The primary outcome was the rate of complications of trochleoplasty procedures. Complications were defined as: a negative outcome including returning to the operating room (OR), symptomatic hardware, loss of range of motion (ROM), increased pain/apprehension leading to return to the OR, patella redislocation/subluxation/instability, accelerated (radiological) progression of patellofemoral osteoarthritis (PF OA), deep venous thrombosis (DVT), infection, distal femoral fracture. Complications were subdivided in minor or major complications. Minor complications included complaints of recurrence of maltracking or subluxation,

loss of up to 20° ROM not requiring surgical treatment, increase in PF OA to grade 2 or 3 according to Iwano classification, superficial wound infection, anesthetic complications. Major complications included redislocation of the patella, return to OR due to increase in pain or recurrence of instability or any other cause, reduced ROM requiring arthrolysis, hardware removal because of pain or crepitus, progression to grade 4 PF OA, venous thrombotic event. Residual pain, swelling or crepitus not leading to OR were considered outcomes of the procedure and not complications.

Data collection and analysis

Data were extracted from the included articles by two reviewers (JvS, SvdG) and included: study ID, number of patients, number of knees, type of trochlear dysplasia, duration of symptoms, indication for surgery, mean patient age at surgery, patient sex, previous surgery on the involved knee, type of trochleoplasty performed, additional procedures performed, type and rate of complications and (if mentioned) time when complication occurred, length of follow-up and patients lost to follow-up. In studies that reported only percentages of complications and no absolute numbers, absolute numbers of complications were calculated based on the number of patients or surgical procedures reported. Subsequently a meta-analysis was performed whenever three or more studies per surgical technique that reported on a type of complication could be included. Despite anticipated heterogeneity, the individual study proportions were pooled. Pooled estimates of proportions with their corresponding 95% confidence intervals were calculated using Freeman-Tukey double arcsine transformation within a random effects model framework. Heterogeneity of combined study results was assessed by I^2, and its connected chi-square test for heterogeneity, and the corresponding 95% confidence intervals were calculated. Restricted maximum likelihood was used to estimate the heterogeneity variance. Statistical analyses were performed using R version 3.4.0 (R Foundation for Statistical Computing, Vienna, Austria) with package 'meta'.

Quality assessment

Quality assessment was not performed as the included articles were retrospective or prospective single-arm cohort studies and no validated scores for the methodological quality of these type of studies are available.

Results

The search strategy retrieved 1,848 unique records. Subsequent selection procedure resulted in 55 eligible articles of which 20 studies could be included in this systematic review (Fig. 1).

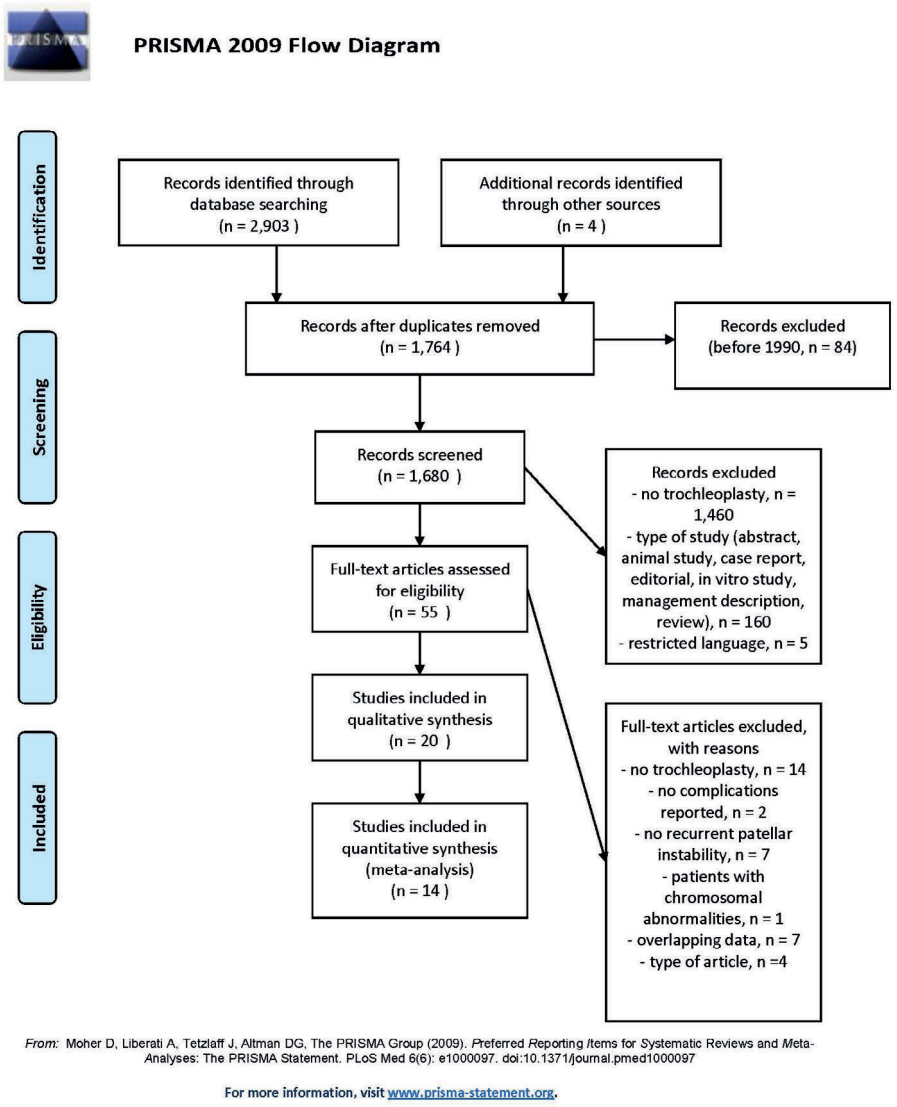

Figure 1. PRISMA flow diagram

Table 1 displays study characteristics including population description, type of trochleoplasty performed, additional procedures performed, and the number of complications.

Table 1. Study characteristics (can be found as attachment to this thesis).

Trochleoplasty procedures were performed on 822 knees in 739 patients. Average age of the patients was 22.6 years (range 12 – 53 years). Sixty-seven percent of patients were female. Mean follow-up was 57 months, mean follow-up in individual studies ranged from 12 months to 183 months (16 studies reported mean, 2 medians, 1 range and 1 a minimum of 1 year).

Indications for trochleoplasty were recurrent patellar instability, defined as at least 2 patellar dislocations (in 1 study based on 1 documented patellar dislocation [13]), with underlying trochlear dysplasia. Ten studies [2, 13-21] reported trochlear dysplasia defined according to the Dejour classification of trochlear dysplasia [22] on conventional X-rays or MRI. In two studies, an elevated trochlear boss height on X-ray was additionally required as indication [13, 20]. For some studies indication was also based on presence of the apprehension sign or lateral patellar glide test [2, 14, 15, 17, 21, 23].

All studies reported that additional procedures were performed, except the one of Bereiter [8] that did not report on additional procedures. On average 46% of patients had undergone previous procedures before trochleoplasty including modified Fulkerson-Elmsie Trillat osteotomy, diagnostic arthroscopy, arthroscopic/open lateral release, tibial tubercle transfer, VMO-plasty, Roux-Goldthwaite procedure and chondroplasty.

A total of 190 complications occurred in 822 knees, including recurrence of instability (subluxation and dislocation), loss of knee range of motion, development or progression of PF OA, return to OR and miscellaneous surgical complications, such as wound complications.

A lateral facet elevating trochlear osteotomy was reported by 2 studies [24, 25]. A deepening trochleoplasty was reported by 17 studies: ten reported on a (modified) Bereiter trochleoplasty [8, 14, 17, 21, 23, 26-30], five on a (modified) Dejour trochleoplasty [2, 13, 16, 18, 31], one on an arthroscopic technique [15], and one on a 'modified' technique [20]. A recession wedge trochleoplasty was reported by one study [19].

Complications and miscellaneous results of techniques included in the meta-analysis

Meta-analysis could be performed for the complications recurrence of patellar instability (subluxations), recurrent dislocation, PF OA, and further surgery needed for the Dejour and Bereiter trochleoplasty techniques only. Meta-analysis for loss of ROM could only be performed for the Bereiter trochleoplasty. Figures 2-5 show the results of the meta-analyses, including proportion of patients with recurrent dislocation (Figure 2), recurrent instability (Figure 3), PF OA (Figure 4) and need for further surgery (Figure 5). The indications for further surgery were not included in the meta-analysis. For the Bereiter trochleoplasty these were medial subluxation in one patient, reduced ROM in six patients, persistent pain in three patients and recurrence of instability in three patients. For the Dejour trochleoplasty these

numbers were complaints of crepitus in two patients, recurrence of instability in ten patients, reduced ROM in twenty-four patients, persistent pain in one patient, PF OA in six patients, loose absorbable screw heads in two patients, hardware breakage in two patients and a trochlear notch osteophyte in one patient. The proportion of patients with loss of ROM which needed intervention is shown in Figure 6.

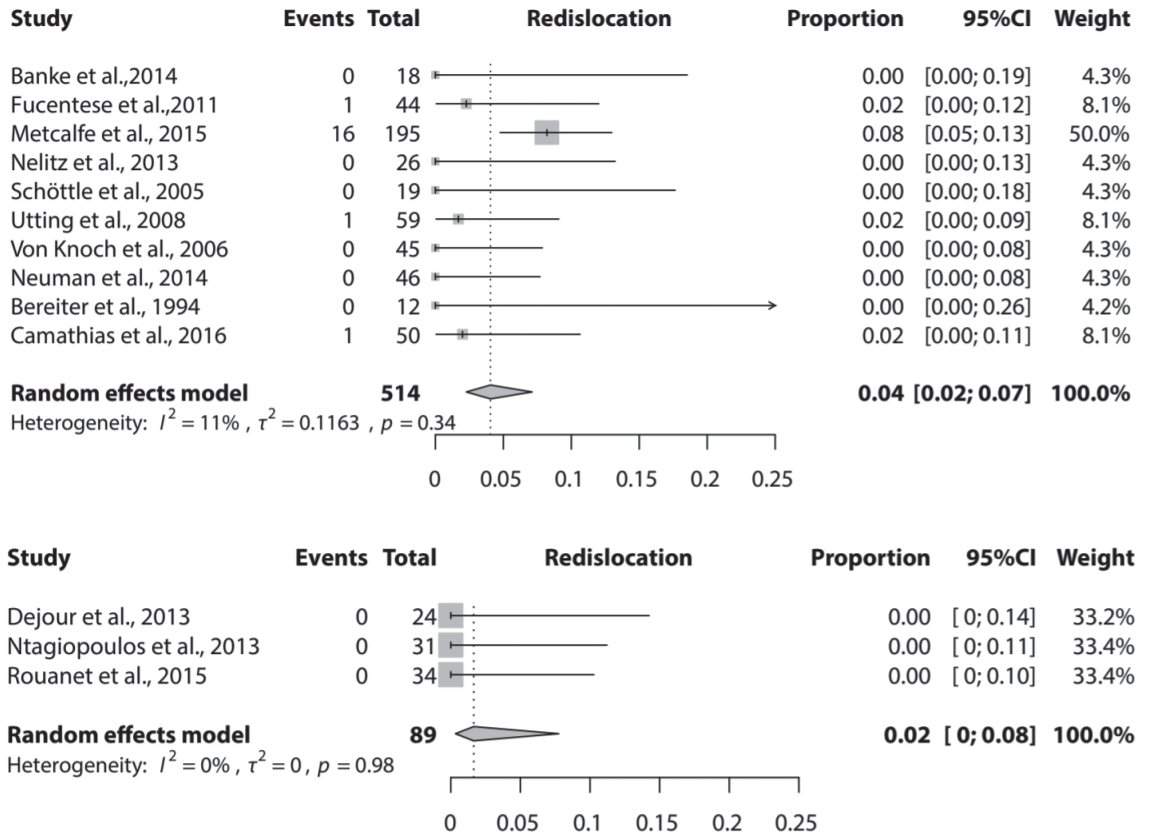

Figure 2. Forest plot of proportion of recurrent dislocation after a Bereiter trochleoplasty (upper) and Dejour trochleoplasty (lower).

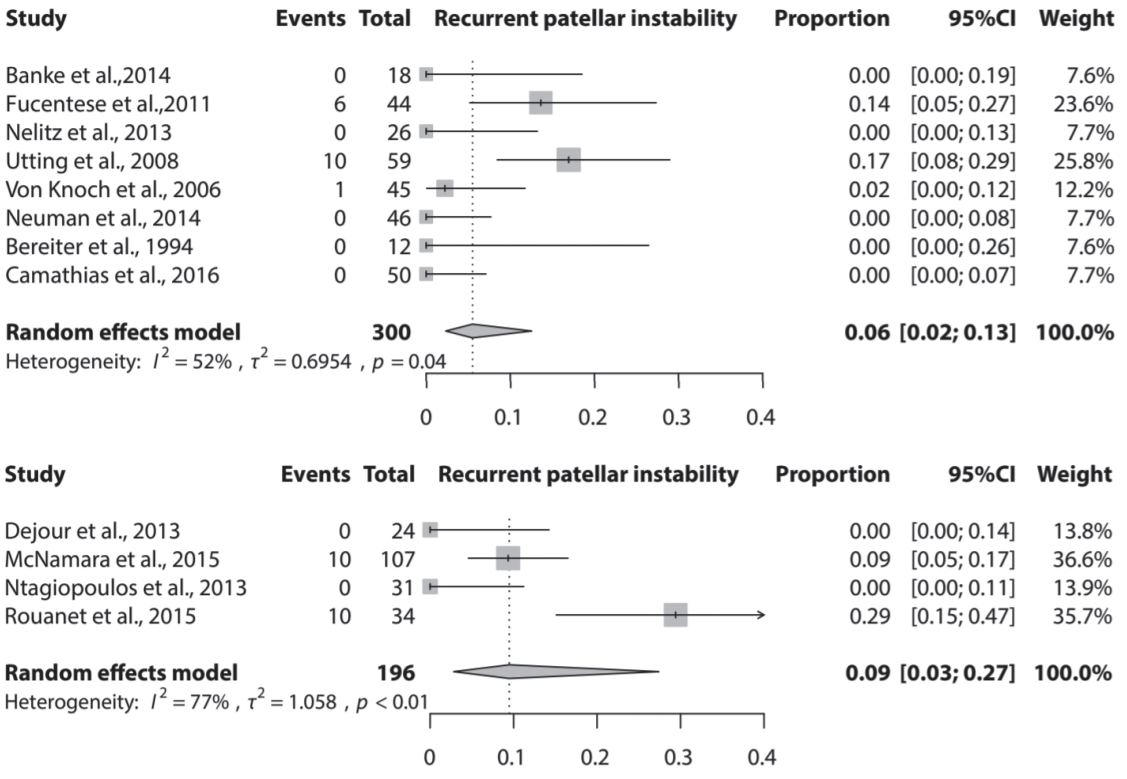

Figure 3. Forest plot of proportion of recurrent patellar instability after a Bereiter trochleoplasty (upper) and Dejour trochleoplasty (lower).

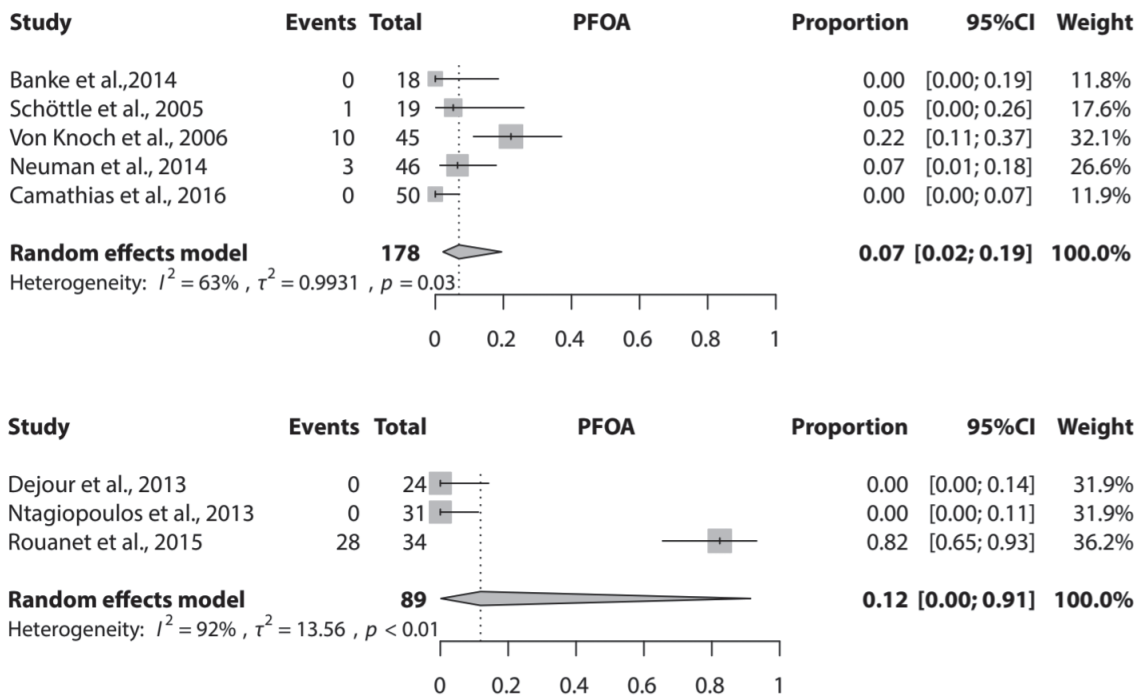

Figure 4. Forest plot of proportion of patellofemoral osteoarthritis (PF OA) after a Bereiter trochleoplasty (upper) and Dejour trochleoplasty (lower).

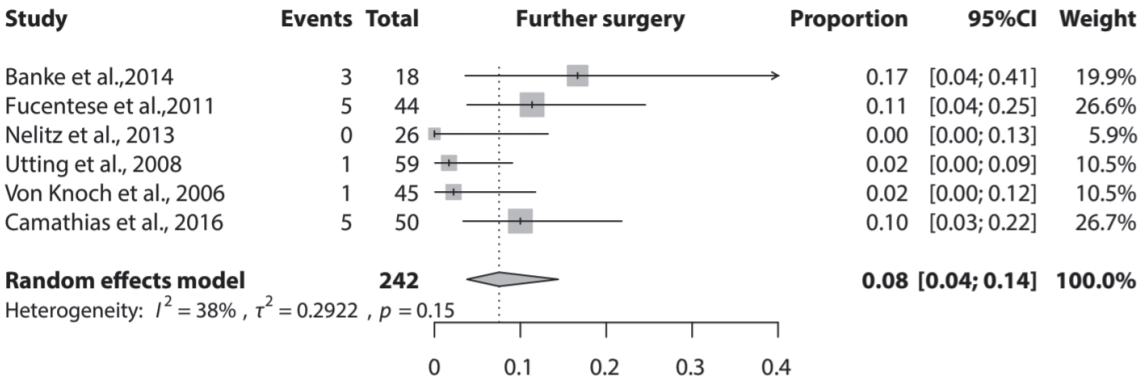

Figure 5. Forest plot of proportion of patients who needed further surgery after a Bereiter trochleoplasty (upper) and Dejour trochleoplasty (lower).

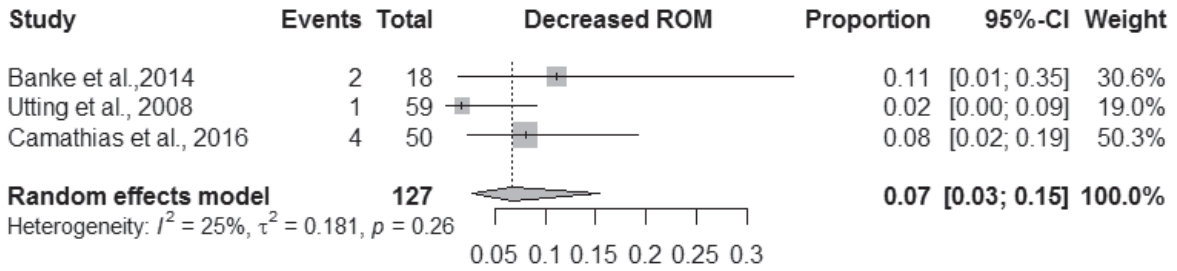

Figure 6. Forest plot of proportion of patients with loss of range of motion after a Bereiter trochleoplasty.

Included in the major complications but not included in the meta-analysis is a pulmonary embolus in one patient in the study of McNamara et al.[13] Minor complications not included in the meta-analysis are a superficial wound infection in two patients in the study of Utting [28] and in four patients in the study of McNamara[13], a deep venous thrombosis in two patients [2, 13], a complication related to anesthesia in two patients [17, 28], a wound healing problem in one patient [17], a complex regional pain syndrome in two patients [8, 17] and a postoperative bleeding in one patient[8]. Fifty-eight patients had unchanged or increased pain not requiring reoperation, ninety-five patients have some residual symptoms such as clicking, swelling or pain. Six patients kept complaints of crepitus without further surgical treatment and fourteen patients kept complaints of swelling.

Complications and miscellaneous results of techniques not included in the meta-analysis

Two studies reported on a lateral facet elevating trochlear osteotomy, one study reported an arthroscopic deepening trochleoplasty, one a modified deepening trochleoplasty, and one a recession wedge trochleoplasty (Table 1).

Discussion

The most important finding of this study was that Bereiter and Dejour trochleoplasty procedures show complication rates similar to other patellar stabilizing procedures. The rates of reoperation after a Bereiter and Dejour trochleoplasty (0.08 (95%CI 0.04;0.14) and 0.20 (95%CI 0.11;0.32)) are comparable with those found in other systematic reviews of patellar stabilizing procedures (4.1% after MPFL-reconstruction [32], 18% after tibial tubercle osteotomy [33] and 25% after trochleoplasty vs. 7% after MPFL-reconstruction[34]). Decreased range of motion and recurrence of instability were the two most frequent reasons for further surgery. The study of McNamara et al. [13] largely contributed (23 patients) to the number of patients returning to the OR after a Dejour trochleoplasty. Ten of these patients underwent an additional MPFL reconstruction and eight underwent arthrolysis. Seven of the eight patients undergoing arthrolysis were from their early cohort of patients before continuous passive motion was introduced. This study of McNamara et al. might therefore confound the rate of reoperation after a Dejour trochleoplasty.

The proportion of recurrent dislocation after a Bereiter or Dejour trochleoplasty (0.04 (95%CI 0.02 - 0.07) and 0.02 (95%CI 0 - 0.08)) was lower than or equal with previous results in literature [32, 35, 36]. In their systematic review, Smith et al. [1] found 13% recurrent patellar dislocations after 2 to 5 years follow-up after surgical intervention for patellar dislocation. Meta-analysis showed that the proportion of recurrence of instability (sensation of instability or subluxation) was low for Bereiter (0.06 (95%CI 0.02-0.13)) and Dejour (0.09 (95%CI 0.03-0.27)) trochleoplasty.

This is low compared with the natural course after patellar dislocation, or patients treated non-surgically being up to 24% according to Smith et al. [1, 37, 38]. From these results, it could be hypothesized that these two trochleoplasty techniques are successful in preventing recurrent dislocation and/or instability symptoms, also compared with other surgical interventions.

Seven studies did not report about the presence of PF OA. The rate of development of PF OA would probably increase at longer follow-up, as the development and progression of PF OA in these patients depends on multiple factors, not only a stable patella. Registration of patellofemoral osteoarthritic changes on imaging does not mean that patients have complaints related to PF OA. The number of PF OA should be interpreted as an objective outcome measure and not as a clinically relevant outcome measure if it is asymptomatic. Most of the studies included in this review were not designed to detect PF OA as an outcome measure. The proportion presented in our results could be an underestimation of the true incidence of PF OA and should be interpreted with caution.

Rare complications that were reported include medial subluxation [14] , patella baja [23] and venous thrombotic events [2, 13], none were catastrophic. There was no mortality associated with trochleoplasty. One should be aware that these and potential other rare complications can occur after a trochleoplasty since it is a very complex procedure.

Some potential limitations of our study have to be discussed. Despite the heterogeneity of the cohorts between studies of different techniques a meta-analysis was performed. Since no comparative studies are included, no direct comparison between different techniques could be made. No conclusion can be drawn as to whether one of the techniques is superior to the other in terms of complications of surgery. Furthermore, there is no clear consensus on the indication for trochleoplasty surgery, which makes a direct comparison between studies and/or techniques very difficult. The presented complications for different techniques should be interpreted in the context of the individual studies that have been published, including exact indication for surgery, duration and severity of symptoms, and patient factors.

The definition of complications is always arguable and will differ between different clinicians and patients. Mild residual symptoms such as pain, swelling or clicking were classified as an outcome of surgery and not as complication of surgery. Some complications cannot be definitely assigned to either the trochleoplasty or the additional procedure, this introduces most likely some bias in complication rate.

It should be noted that the absence of complications does not mean that a patient is free of complaints. The rate of complications found in this review is acceptable, but trochleoplasty is still a rather radical surgical procedure with significant risks.

Almost all studies were retrospective or prospective case series. None of the studies were randomized or described a difference between two cohorts. Because of this lack of methodological quality, we did not perform a quality assessment; all studies were regarded low-level evidence.

Publication bias may be present since "negative" results of case series of surgical procedures are less likely to be submitted for publication. Measurement bias may have occurred due to failure of thorough administration of complications, especially for minor complications in retrospective studies also due to diligence and increased awareness of the screening resulting in higher report of complications.

There might also be sampling bias, since most surgeons who performed trochleoplasty in the articles in this review were experienced surgeons, thus the number of complications might be an underestimation of the true number.

With the limited high-quality evidence available, we think the results of this study a sufficiently accurate represent the complication rate after trochleoplasty procedures including any additional procedures.

Conclusions

This systematic review and meta-analysis demonstrates that the complications after a Bereiter and Dejour trochleoplasty including additional procedures are in the range of those of other patellar stabilizing procedures. For four other techniques, no meta-analysis could be performed.

Competing interests
We have received no funding for this study and have no competing interests to declare.

Authors' contributions
JvS, SvdG, NV and GH designed the study and drafted the research protocol. JvS and SvdG performed the literature search, selection, data extraction and drafted the manuscript. JvS and GH developed the search strategy and performed the data analysis. JvS, SvdG, NV and GH contributed in the interpretation of the data. SvdG gave final approval of the version to be submitted.

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Appendix

Pubmed search:
(("Patellar Dislocation"[Mesh] OR ("Patella"[Mesh] AND "Dislocations"[Mesh]) OR ((patella*[tw] OR patello*[tw] OR trochlea*[tw]) AND (dislocat*[tw] OR instability[tw] OR instabilities[tw] OR instable[tw] OR luxation*[tw] OR subluxation*[tw]))) AND (trochleo*[tw] OR trochlea*[tw] OR Sulcus[tw] OR patellar groove[tw] OR patellar dislocation/surgery)) OR patellar dislocation/complications.

Embase and Web of Science search terms:
((Patella dislocation/ OR (exp patella/ AND exp dislocation)) OR ((patella* or patella* or trochlea) AND (dislocate* or instability or instabilities or instable or luxation* or subluxation*))ti.ab.kw.) AND ((trochlea* or trochleo*).ti.ab.kw. OR sulcus ti.ab.kw. OR patella dislocation/surgery) OR patella dislocation/complication. Limits: conference abstract or conference proceeding

Cochrane Library search:
Patellar Dislocation [MeSH] OR (Patella [MeSH] AND Dislocations [MeSH]) OR ((patella* or patella* or trochlea) AND (dislocate* or instability or instabilities or instable or luxation* or subluxation*))

List of abbreviations
CPM: continuous passive motion

DVT: deep venous thrombosis

MPFL: medial patellofemoral ligament

MRI: magnetic resonance imaging

OR: operating room

PE: pulmonary embolism

PF OA: patellofemoral osteoarthritis

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

ROM: range of motion

VMO: vastus medialis obliquus

CHAPTER 8

DUTCH TRANSLATION AND VALIDATION OF THE NORWICH PATELLAR INSTABILITY SCORE AND BANFF PATELLA INSTABILITY INSTRUMENT IN PATIENTS AFTER SURGERY FOR PATELLAR INSTABILITY

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Abstract

Purpose
Recently, two new English specific patient reported outcome measures (PROMs) to evaluate treatment of patients with patellofemoral complaints have been developed: the Banff Patella Instability Instrument (BPII) and the Norwich Patellar Instability (NPI) score. This study was designed to translate and validate the BPII and NPI in Dutch patients after surgical treatment for patellar instability.

Methods
Forward and backward translation of the outcome measures was performed. Patients who had been surgically treated for patellar instability filled out the NPI and BPII together with the Kujala Knee Score, numeric rating scales, Knee disability and Osteoarthritis Outcome Score (KOOS) and SF-36. We assessed internal consistency and construct validity. We evaluated the presence of ceiling and floor effects.

Results
Ninety-seven patients completed the online questionnaires. The internal consistency of the NPI and BPII score was excellent for both outcome measures. The BPII and NPI had good correlations with other PROMs. For the BPII we found no floor nor ceiling effect. For the NPI we found a floor effect but no ceiling effect.

Conclusion
Our results indicate that the Dutch version of the BPII and the NPI can be used for patients with patellar instability. Both PROMs have specific (dis)advantages.

Keywords
Patellofemoral instability, patient reported outcome measures, BANFF, Norwich, anterior knee pain

Introduction

Instability of the patella may lead to serious impairment and most patients seek doctors advise how to best treat their complaints. To evaluate outcome of treatment of these patients, knee specific patient reported outcome measures can be used. Historically, [1] the modified International Knee Documentation Committee (IKDC) knee ligament standard evaluation form [2], Kujala anterior knee pain scale [3], Knee disability and Osteoarthritis Outcome Score (KOOS) [4], Lysholm knee scoring scale [5] and Short Form-36 (SF-36) [6] were used. Smith et al. [7] stated that: "there is no outcome that is clinically meaningful" because the reliability and validity of these measurements for this patient category is poor. Recently two new outcome measures have been developed. Hiemstra et al. [8] devised the Banff Patella Instability Instrument (BPII). Validation of this outcome measure was performed in a Canadian population of patients with recurrent patella dislocations in whom non-surgical management had failed. The authors evaluated the score according to the Consensus based Standards for the Selection of Health Measurements Instruments (COSMIN) guidelines [9, 10] and demonstrated good face and content validity, high internal consistency, excellent reliability and construct validity in their population [8]. Concurrent validation, responsiveness and factor analysis and item reduction of the BPII lead to the creation of the BPII 2.0 [11]. Another recently introduced score, the Norwich Patellar Instability (NPI) score [12], was validated on patients with patellar instability, either preoperatively or postoperatively. The initial results of the COSMIN guidelines criteria for this score indicated a good convergent and divergent validity and high internal consistency [12]. In a second validation study the score showed a high convergent validity, internal consistency and good concurrent validity. [13]

An essential requirement of all measurements in clinical practice and research is that they are reliable and valid. Reliability is defined as 'the degree to which the measurement is free from measurement error' [14]. Validity is defined as 'the degree to which an instrument truly measures the construct it purports to measure'.[14]

A Dutch validated subjective outcome score for patients with patella instability and patellofemoral pain is lacking. It would allow for the determination of the efficacy of a specific treatment, and for comparison of different methods of treatment in patients with the same disorder. Furthermore, it may enable clinicians to follow the progress of patients before and after a particular treatment.

This study was designed to translate and validate the BPII and NPI in Dutch, with patients who have undergone surgical treatment for patellar instability and evaluate the internal consistency, construct validity and ceiling or floor effects.

Methods

This study was presented to the institutional review board who deemed that the Medical Research Involving Human Subjects Act (WMO) does not apply. The translation of the scores was done according to the MAPI method [15]. The original versions of the NPI score and BPII were translated from English to Dutch by two bilingual independent native Dutch persons (a PhD-student and a medical student). In a meeting with a third person (an orthopedic surgeon) discrepancies between these two forward translations were discussed and consensus was achieved. The final Dutch version was translated back into English by an independent (non-medical) native-English speaking person blinded for the original English version of the questionnaires to ensure content validity. Discrepancies between this backward translation and the original version were reviewed and discussed by two researchers, but no inconsistencies were found. In a pilot series clarity, understandability, acceptability of the questionnaire was evaluated in a group of 15 patients before the actual study commenced. No changes were necessary and both PROMs were deemed ready for validation.

Patients data from other retrospective studies in our center was used. All included patients had been surgically treated for patellar instability in Radboudumc between 2005 and 2015. The surgical procedures included trochlear osteotomy, tibial tubercle transposition and/or medial patellofemoral ligament reconstruction. Patients were contacted by letter and by phone for informed consent, after inclusion the patients were directed to a protected website to fill out several patients reported outcome measures (PROMs). All questionnaires contained the translated Norwich patella instability score and Banff patella instability instrument, a validated Dutch version of the Kujala Knee Score (KKS)[16], Knee disability and Osteoarthritis Outcome Score (KOOS)[4], SF-36[6] and a Numeric Rating Scale (NRS) for pain and disability for determination of the construct validity.

The Banff Patella Instability Instrument (BPII) is a disease specific quality of life measurement designed specifically for patients with patellofemoral instability. It is based on the Anterior Cruciate Ligament-Quality of Life questionnaire (ACL-QOL)[17], and contains the following items: symptoms and physical complaints, work, sport/recreation/competition, lifestyle, social and emotional. Each of these items can be scored by the patient on a 0 to 100 scale. Validation studies were done by designers of the instrument with patients not responding to conservative treatment who were referred for orthopedic consultation to consider operative treatment. For the English version the clinimetric and psychometric soundness of the scores were tested: content validity, internal consistency, floor and ceiling effect, test-retest [8], concurrent validation to other scores [18] and to objective clinical measurements. The score has not been evaluated by other users. For this paper, the original 32 item score was used. After a recent factor analysis study a reduced 23 item version was published, but this was unavailable at the time of the current study.

The Norwich Patella Instability score (NPI) consists of 19 items scoring instability for lower-and higher-energy activities to assess perceived patellar instability. It was based on a previous study assessing activities the aggravated symptoms in patients with patella instability [19] All patients in the validations study had at least one patella dislocation. The score consists of a five-point Likert scale ranging from 'always' to 'never'. The score is ranges from 0 to 250. The total score is then converted to a percentage based on the number of scored responses provided. A higher percentage indicates higher severity of patellar instability.

The SF-36 is a patient-administered, generic HRQL (health related quality of life) instrument. It comprises 36 items across eight dimensions (physical functioning, role/emotional functioning, role/social functioning, role physical/functioning, bodily pain, vitality, general health and mental health perceptions. The eight dimensions of the SF-36 score are calculated on a 0 to 100 scale (100 indicating no symptoms and 0 indicating extreme symptoms).

The Kujala Knee Score investigates 13 domains. The score ranges from 0-100 with a higher score indicating better performance.

The KOOS is a 40-item questionnaire for evaluating symptoms and restrictions in patients with knee related complaints. The questions cover five domains; symptoms (5 items), pain (10 items), activities of daily living (17 items), sports and recreation (4 items) and quality of life (4 items). Answers are on a 5-point Likert scale. Higher scores related to fewer complaints. The NRS was obtained through a horizontal line of 100 mm. Two dimensions of pain will be assessed; pain during activity and pain at resting. Additionally, an NRS will be used to assess instability and disability resulting from patellofemoral pain over the last week. The patient was free to put a digital point on the line. This point was transferred to a length from 0 to that point in millimeters. A NRS score of 0 meant no pain, no disabilities and a score of 100 meant worst pain and fully disabled respectively.

As measure of reliability we assessed internal consistency (the degree of interrelatedness among the items). It qualifies the extent to which items assess the same construct and is quantified using Cronbach's alpha test, which ranges from 0 to 1. A value of more than 0.7 is considered acceptable [20].

The Dutch NPI and BPII were compared to the SF-36, NRS scores for pain and disability, Kujala and the KOOS. The Spearman correlation tests was calculated for the assessment of construct validity. Convergent validity was tested by hypothesizing strong ($r>0.5$) (Spearman) correlations between the NPI or BPII and questionnaires that measure similar constructs like the KKS, KOOS and three physical domains of the SF36 (physical functioning, role limitations due to physical problems, bodily pain). Divergent validity will be tested by hypothesizing weak ($r<0.3$) correlations between the NPI or BPII and questionnaires that are expect to measure different constructs, like the mental domains of the SF36.

The presence of ceiling and floor effects was evaluated using the percentages of patients having the maximum or minimum score. We used the definition by Terwee [21] : there are no floor or ceiling effects if less than 15% of patients have minimum or maximum score.

Results

Ninety-seven patients filled out and completed the online questionnaires. The average time after surgery was 56 months (range 8 to 127 months). The descriptive of the scores are presented in table 1. The internal consistency of the NPI and BPII score was excellent with a Cronbach's α of 0.972, and of 0.967 respectively.

	Mean (SD)	Median (min-max)	% Floor	% Ceiling
NPI Score	25 (23)	22 (0-87)	***17***	0
Banff	58 (22)	55 (10-100)	0	1
Kujala	73 (19)	77 (25-100)	***0***	5
NRS pain active	33 (28)	30 (0-100)	***23***	1
NRS pain rest	15 (21)	0 (0-80)	***55***	0
NRS disability	24 (26)	12 (0-95)	***18***	0
NRS instability	36 (33)	30 (0-100)	12	2
NRS satisfaction	70 (32)	80 (0-100)	6	***23***
KOOS symptoms	77 (19)	79 (14-100)	0	12
KOOS pain	79 (22)	86 (11-100)	0	***20***
KOOS ADL	85 (20)	93 (12-100)	0	***26***
KOOS Sports	47 (31)	45 (0-100)	10	8
KOOS QoL	56 (24)	50 (0-100)	2	***6***
SF 36 PF	76 (22)	80 (10-100)	0	***15***
SF 36 RP	80 (33)	100 (0-100)	9	***66***
SF 36 RE	89 (27)	100 (0-100)	6	***83***
SF 36 SF	85 (18)	88 (38-100)	0	***50***
SF 36 MH	63 (15)	60 (24-100)	0	2
SF 36 VT	69 (19)	70 (20-100)	0	5
SF 36 BP	75 (22)	78 (10-100)	2	***20***
SF 36 GH	73 (23)	80 (10-100)	0	7

Table 1. Mean outcome of the scores.

Floor and ceiling effects are present if % floor or % ceiling >15% (bold italic numbers). ADL Activities of daily living, QoL quality of life, PF physical functioning, SF social functioning, RP role limitation resulting from physical problems, RE role limitation resulting from emotional problems, MH mental health, VT energy vitality, BP bodily pain, GH general health perception.

Spearman correlation coefficients are presented in table 2. The criteria set for convergent validity for the BPII was met with strong correlations for SF 36 subscales

physical functioning (ρ = 0.64) and bodily pain (0.60), all KOOS sub-scales and with the KKS (ρ =0.83), but not for role limitations due to physical problems (ρ=0.49). The criteria set for divergent validity was not met for SF 36 sub-scale social functioning (ρ=0.45) but was met for sub-scale mental health (ρ=0.25). For the BPII we found no floor nor ceiling effect. For two specific question of BPII answers were frequently missing: for question 6 the response rate was only 74%, for question 18 the response rate was 72%. The response rate for the other questions was 100%.

	BPII	NPI
Kujala Knee Score	0.83	-0.78
KOOS symptoms	0.60	-0.58
KOOS pain	0.73	-0.69
KOOS ADL	0.74	-0.72
KOOS Sports	0.73	-0.76
KOOS QoL	0.85	-0.72
SF 36 PF	0.64	-0.60
SF 36 RP	0.49	-0.25
SF 36 RE	0.19	-0.003
SF 36 SF	0.45	-0.23
SF 36 MH	0.25	-0.10
SF 36 VT	0.39	-0.20
SF 36 BP	0.61	-0.55
SF 36 GH	0.35	-0.28

Table 2. Spearman's rho correlation coefficient between BPII or NPI respectively and the other outcome measurements.
ADL Activities of daily living, QoL quality of life, PF physical functioning, SF social functioning, RP role limitation resulting from physical problems, RE role limitation resulting from emotional problems, MH mental health, VT energy vitality, BP bodily pain, GH general health perception.

The criteria set for convergent validity for the NPI met with strong correlations for SF 36 subscales physical functioning (ρ =-0.60), bodily pain (ρ =-0.55), all KOOS subscales and with the KKS (ρ =-0.78) , but not for role limitations due to physical problems (ρ=-0.25). The criteria set for divergent validity were met with weak correlations for SF 36 subscales social functioning (ρ=-0.23) and mental health (ρ =-0.10). For the NPI we found a floor effect but no ceiling effect. For 6 questions of the NPI data was missing: for question 2 in 25% of the patients, for question 3 for 23% of the patients, for questions 5 for 26% of the patients, for question 6 for 19% of the patients, for questions 7 for 18% of the patients and for question 8 for 17% of the patients.

Discussion

The most important finding of this study was that the NPI score and the BPII demonstrated good reliabyutility in patients after surgery for patellar instability. This is the first study to translate the Norwich Patellar Instability score and Banff Patellar Instability Instrument to Dutch and validate it for use in patients treated for patellar instability. Cronbach's alpha was calculated to evaluate internal consistency, it was excellent for both the NPI and BPII. This is in concordance with previous validation studies of these measurements [8, 12, 13, 18]. Cronbach's alpha depends on the number of items in a questionnaire and on the variation in the population, since BPII consists of more items, one could expect Cronbach's alpha is higher in the BPII than in the NPI, but our data does not support this. The high values indicate that the scores measure an unified construct, but also that there is a redundancy in the measurement and both scores could perhaps be shortened. Various questions in both scores were left unanswered. This may indicate that the wording of the questions was unclear, but also that patients experienced that the questionnaire is too long or seems repetitive.

Floor and ceiling effects are measures of content validity of a questionnaire, low effects are desired in instruments with good content validity [22]. NRS pain at rest had a large floor effect. There was a large ceiling effects for SF36 RP, RE and SF and a small ceiling effect for KOOS ADL. The ceiling effects of these scores make them clinically less meaningful for evaluation and follow up since patient's clinical improvement cannot be quantified by the scores. This is worrisome, especially in the light of improving clinical patient outcomes. The floor effect of the NPI is in concordance with the results of Smith et al. [13], and demands future study assessing appropriateness of the questions in the NPI which demonstrated this floor effect.

Both the Dutch BPII and the NPI scores had fairly good correlation with almost all other scores. The correlation was strongest with the KKS, as one would expect because all three scores are specifically designed for patients with patellofemoral complaints. There was a moderate correlation with other the knee specific outcome scores, the KOOS, on all subscales. For the non-specific scores (SF36, NRS), the correlation was acceptable. Only the SF36 sub-scale limitations due to physical problems showed poor correlation with the Dutch BPII and NPI (convergent validity, $\rho>0.5$), and the SF 36 subscale social functioning correlated poorly with the BPII (divergent validity, $\rho<0.3$).

Conclusion

The results of this study indicate that the Dutch version of the BPII and the NPI can be used for patients with patellar instability. The BPII is rather long, this might limit its routine use. The NPI score has a floor effect, resulting in limitations in

its usefulness. The best PROM pertaining to patellofemoral instability patients has yet to be found. This is mandatory to quantify the disability and impairment, evaluation after treatment and mid- and long- term follow up after surgery.

Competing interests
We have received no funding for this study and have no competing interests to declare.

Authors' contributions
SK initiated the study by defining the research question and purpose of the study. JvS performed data collection and analysis and drafted the manuscript. SK was the first author to review drafts of the manuscript and gave final approval of the version to be submitted. SvdG was second reviewer of drafts of the article and added important feedback for interpretation of the results and for discussion section.

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Appendices

Supplemental 1. Banff patella instability instrument

INSTRUCTIE

Beantwoord alle vragen over de huidige staat, functie en omstandigheden van uw knie met de instabiele knieschijf en uw gedachten hierover. De vragen gaan over de laatste drie maanden.

Geef met een schuine streep (/) op de lijn aan welk punt (van 0 tot 100) het beste uw huidige situatie weergeeft. (digitaal: sleep de schuine lijn)

Bijvoorbeeld:

Is dit een goede vragenlijst?

0 **100**

Nutteloos Fantastisch

Als u de schuine streep in het midden van de lijn plaatst, betekent dit dat de vragenlijst van gemiddelde kwaliteit is, met andere woorden de kwaliteit van de lijst bevindt zich in het midden tussen nutteloos en fantastisch. Als de beschrijving aan het einde van de lijn de huidige situatie het best beschrijft, zet u de schuine streep aan het uiteinde van de lijn.

De eerste vier vragen gaan over uw **SYMPTOMEN & LICHAMELIJKE KLACHTEN**.

1. Met betrekking tot het algeheel functioneren van uw knie, hoeveel last heeft u van "instabiliteit (door de knie gaan)"?

(Plaats een schuine streep aan het rechter uiteinde als u geen instabiliteit ervaart (nooit door de knie gaat). Deze vraag bestaat uit twee delen: de ernst van de instabiliteit (1a) en de frequentie (1b) van de instabiliteit.

1a

0 **100**

Momenten van erg door de knie gaan Momenten van licht door de knie gaan

1b

0 **100**

Continu door de knie gaan Nooit door de knie gaan

2. Hoe veel pijn of ongemak ervaart u in uw knie bij elke vorm van langdurige (langer dan een half uur) activiteit?

0 ——— **100**

Ernstige pijn Totaal geen pijn

3. Met betrekking tot het algeheel functioneren van uw knie, hoeveel last heeft u door stijfheid of verminderde beweeglijkheid van uw knie?

0 ——— **100**

Ernstige last Totaal geen last

4. Beschouw het functioneren van uw knie in zijn geheel en hoe dit in verhouding staat tot de kracht van uw spieren: Hoe zwak is uw knie dan?

0 ——— **100**

Extreem zwak Totaal niet zwak

De volgende vragen gaan over uw werk of beroep. De vragen betreffen uw vermogen om goed te functioneren op het werk en hoe uw knie daar invloed op heeft.

Als u een voltijd student of huisvrouw/-man bent, gaan de vragen hierover. Indien u daarbij deeltijd werkt, gaat het over beide situaties. De vragen gaan over de laatste drie maanden.

***** Als u MOMENTEEL GEEN WERK heeft door een ANDERE REDEN DAN UW KNIE, plaats dan hier een kruisje. _____**

5. Hoeveel last heeft u door uw knie bij het draaien of het maken van draaiende bewegingen op het werk (pivoteren)? (Plaats een schuine streep aan

0 ——— **100**

het linker uiteinde als u niet kan werken door uw knie)

0 ——— **100**

Ernstige last Totaal geen last

6. Hoeveel last heeft u vanwege uw knie bij het hurken op uw werk?

(Plaats een schuine streep aan het linker uiteinde als u niet kan werken door uw knie)

0 ——————————————— **100**

Ernstige last Totaal geen last

7. Hoe erg is het voor u als u niet kunt werken vanwege problemen met uw knie? (Plaats een schuine streep aan het linker uiteinde als u niet kan werken door uw knie)

0 ——————————————— **100**

Ernstige last Totaal geen last

8. Hoe erg is het voor u als u tijd op school of werk mist, vanwege de behandeling van uw knie?

0 ——————————————— **100**

Ernstige last Totaal geen last

De volgende vragen gaan over uw **VRIJETIJDSBESTEDING EN SPORT**. De vragen hebben betrekking op de invloed van uw knieklachten op uw vermogen tot functioneren en deelname aan deze activiteiten. De vragen hebben betrekking op de laatste drie maanden.

9. Hoe beperkt bent u bij plotseling draaien of van richting veranderen?

0 ——————————————— **100**

Volledig beperkt Niet beperkt

10. Hoe erg vindt u het dat sporten of vrijetijdsbesteding mogelijk leiden tot een verslechtering van de toestand van uw knie?

0 ——————————————— **100**

Extreem erg Totaal niet erg

11. Hoe is het niveau van uw huidige sport- of recreatieve prestaties, vergeleken met uw niveau voor de blessure?

0 ——————————————— **100**

Volledig beperkt Niet beperkt

12. In welke mate zijn uw verwachtingen veranderd, vanwege de toestand van uw knie, wat betreft de sporten of activiteiten die u momenteel zou willen doen?

0 **100**

Verwachtingen verlaagd Verwachtingen helemaal niet verlaagd

13. Moet u extra voorzichtig zijn tijdens sporten of recreatieve activiteiten? (plaats een schuine streep aan het linker uiteinde als u niet in staat bent om deze activiteiten uit te voeren door uw knie)

0 **100**

Altijd erg voorzichtig Nooit extra voorzichtig

14. Hoe angstig bent u dat u door uw knie gaat tijdens sporten of recreatieve activiteiten? (plaats een schuine streep aan het linker uiteinde als u niet in staat bent om deze activiteiten uit te voeren door uw knie)

0 **100**

Extreem angstig Totaal niet angstig

15. Maakt u zich zorgen om de omgevingsomstandigheden, zoals een nat grasveld, een harde baan of het type vloer in de zaal, als u sport of beweegt? (plaats een schuine streep aan het linker uiteinde als u niet in staat bent om deze activiteiten uit te voeren door uw knie)

0 **100**

Ernstige zorgen Totaal geen zorgen

16. Vindt u het frustrerend om rekening te moeten houden met uw knie tijdens sport of recreatieve activiteiten.

0 **100**

Extreem frustrerend Totaal niet frustrerend

17. Hoe moeilijk is het voor u om voluit te gaan tijdens uw sport of recreatieve activiteiten? (plaats een schuine streep aan het linker uiteinde als u niet in staat bent om deze activiteiten uit te voeren door uw knie)

0 ——————————————————— **100**

Extreem moeilijk Totaal niet moeilijk

18. Bent u bang om contactsporten te spelen? (omcirkel "**n.v.t.**" als u niet aan contactsport doet vanwege andere redenen dan uw knie)

0 ——————————————————— **100**

Extreem bang Totaal niet bang

De volgende vragen gaan specifiek over de twee belangrijkste sporten of recreatieve activiteiten die u beoefent. Noteer ze hieronder in volgorde van belang.

1._____

2._____

19. Hoe beperkt bent u in het beoefenen van uw nummer "1" sport of activiteit? (plaats een schuine streep aan het linker uiteinde als u niet in staat bent om deze activiteiten uit te voeren door uw knie)

0 ——————————————————— **100**

Extreem beperkt Totaal niet beperkt

20. Hoe beperkt bent u in het beoefenen van uw nummer "2" sport of activiteit? (plaats een schuine streep aan het linker uiteinde als u niet in staat bent om deze activiteiten uit te voeren door uw knie)

0 ——————————————————— **100**

Extreem beperkt Totaal niet beperkt

De volgende vragen gaan over uw instabiele knie in het dagelijks leven en moeten apart gezien worden van werk en sport/recreatieve activiteiten.

21. Moet u vanwege uw knie met de instabiele knieschijf rekening houden met betrekking tot veiligheid bij algemene dingen (zoals kleine kinderen optillen, in de tuin werken, etc.)?

0 ——————————————————— **100**

Extreem veel rekening Totaal geen rekening

22. In welke mate is uw vermogen tot inspanning en fit blijven beperkt door uw knieprobleem?

0 ——— **100**

Totaal beperkt Totaal niet beperkt

23. In welke mate is uw levensvreugde verminderd door uw knieprobleem?

0 ——— **100**

Totaal verminderd Niet verminderd

24. Hoe vaak bent u zich bewust van uw knieprobleem?

0 ——— **100**

Constant Nooit

25. Bent u bezorgd om uw knie tijdens alledaagse activiteiten die u samen met uw familie doet?

0 ——— **100**

Extreem bezorgd Totaal niet bezorgd

26. Heeft u uw leefstijl aangepast door potentieel schadelijke activiteiten voor uw knie te vermijden?

0 ——— **100**

Totaal aangepast Niet aangepast

De volgende vragen gaan over uw opvattingen en uw gevoel in relatie tot uw knie met de instabiele knieschijf. De vragen gaan over de laatste drie maanden.

27. Vind u het erg dat u door uw knieproblemen uw competitieve behoeften niet meer kunt realiseren? (Plaats een schuine streep aan het rechter uiteinde (100) als u aan uw competitieve doelstellingen voldoet. Plaats een schuine streep aan het linker uiteinde (0) als u geen competitieve behoeften heeft)

0 ——— **100**

Extreem erg Totaal niet erg

28. Heeft u psychisch moeite gehad om uw knieprobleem te accepteren?

Erg veel moeite Totaal geen moeite

29. Hoe vaak bent u bezorgd over uw knie?

Constant Nooit

30. In welke mate heeft u last van een gebrek aan vertrouwen in uw knie?

Ernstige last Totaal geen last

31. Hoe bang bent u om uw knie opnieuw te blesseren?

Extreem bang Totaal niet bang

Supplemental 2. Norwich patella instability score

Hieronder vindt u een lijst van activiteiten, waarbij u het gevoel kunt hebben dat uw knieschijf 'uit kom de schiet' of instabiel aanvoelt.

Lees allereerst de onderstaande uitspraken en kruis vervolgens het vakje aan dat het beste beschrijft hoe vaak u het gevoel heeft dat uw knieschijf 'uit de kom schiet' of instabiel aanvoelt bij de betreffende activiteit. **(Gelieve één vakje per vraag aan te kruisen).**

1. Draaien/van richting veranderen gedurende sport/spel

Altijd (5)	Vaak(4)	Soms(3)	Zelden(2)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

2. Van richting veranderen tijdens het rennen

Altijd(7)	Vaak(5)	Soms(3)	Zelden(2)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

3. Rechtuit rennen op een *niet vlakke* ondergrond

Altijd(7)	Vaak(5)	Soms(3)	Zelden(2)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

4. Lopen op een gladde, natte of ijzige ondergrond

Altijd(7)	Vaak(5)	Soms(3)	Zelden(2)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

5. Zijwaarts rennen

Altijd(10)	Vaak(7)	Soms(5)	Zelden(3)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

6. Hinkelen

Altijd(10)	Vaak(7)	Soms(5)	Zelden(3)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

7. Springen

Altijd(10)	Vaak(7)	Soms(5)	Zelden(3)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

8. Rechtuit rennen op een *vlakke* ondergrond

Altijd(10)	Vaak(7)	Soms(5)	Zelden(3)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

9. Trap af lopen

Altijd(10)	Vaak(7)	Soms(5)	Zelden(3)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

10. Hurken

Altijd(10)	Vaak(7)	Soms(5)	Zelden(3)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

11. Knielen

Altijd(10)	Vaak(7)	Soms(5)	Zelden(3)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

12. Rechtdoor lopen op een *niet vlakke* ondergrond

Altijd(15)	Vaak(10)	Soms(7)	Zelden(5)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

13. Trap op lopen

Altijd(15)	Vaak(10)	Soms(7)	Zelden(5)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

14. Op of over een hoog opstapje stappen

Altijd(15)	Vaak(10)	Soms(7)	Zelden(5)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

15. Benen over elkaar slaan als je zit

Altijd(15)	Vaak(10)	Soms(7)	Zelden(5)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

16. Rechtdoor lopen op een *vlakke* ondergrond

Altijd(22)	Vaak(15)	Soms(10)	Zelden(7)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

17. In of uit de auto stappen

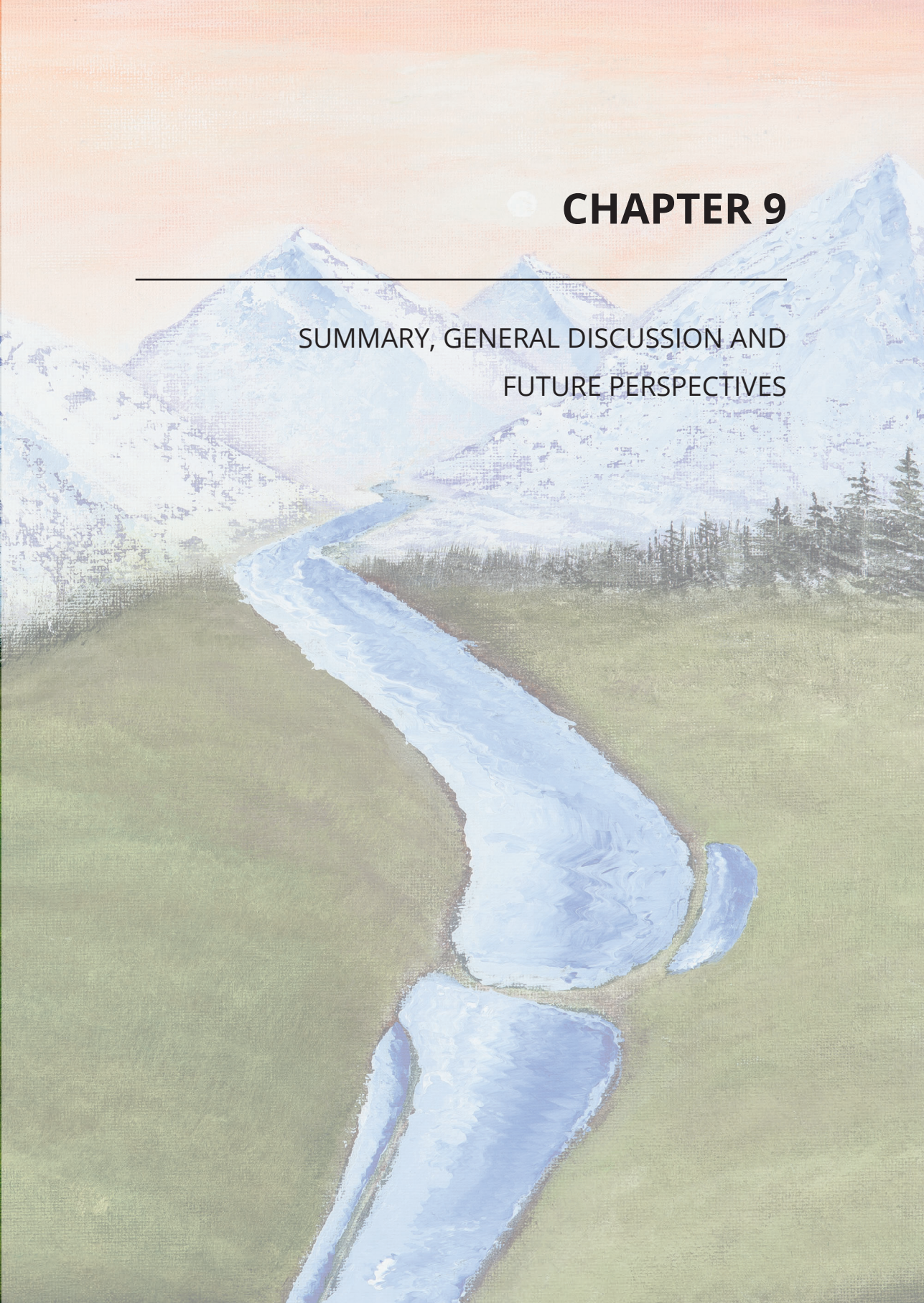
Altijd(22)	Vaak(15)	Soms(10)	Zelden(7)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

18. Een bocht maken met een zwaarbeladen winkelwagen in het gangpad van een supermarkt

Altijd(25)	Vaak(22)	Soms(15)	Zelden(10)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐

19. Draaien om over je schouder te kijken

Altijd(25)	Vaak(22)	Soms(15)	Zelden(10)	Nooit(0)	n.v.t.
☐	☐	☐	☐	☐	☐



CHAPTER 9

SUMMARY, GENERAL DISCUSSION AND FUTURE PERSPECTIVES

The multidimensional character of treatment of patients with patellofemoral instability has been outlined in the general introduction of this thesis. The aim of this thesis was to optimize the treatment of patients with patellofemoral instability by increasing knowledge on certain aspects of treatment. In this chapter, answers to the research questions that were proposed in the introduction will be summarized and discussed by topic. Finally, future perspectives will be outlined.

Imaging

Research question

What is the intra- and interrater reliability of different patellar height measurement methods on conventional radiography, CT and MRI? (Chapter 2)

In Chapter 2 the intra- and interrater reliability of Insall-Salvati ratio (IS), Blackburne-Peel ratio (BP), Caton-Deschamps ratio (CD) and the modified Insall-Salvati ratio (MIS) were determined on conventional radiographs (CR), computational tomography (CT) and magnetic resonance imaging (MRI). The patellotrochlear index (PTI) is a specific measurement for MRI. An inter-method reliability was calculated to compare the results of IS, BP, CD and MIS between different imaging modalities. The IS showed better intra- and inter-observer reliability than the BP, CD and MIS on all imaging modalities. Intra-observer reliability of IS on CR, CT and MRI respectively had an intra-class correlation coefficient (ICC) minimum and maximum of 0.72-0.91, 0.78-0.83, 0.70-0.85. For inter-observer reliability the ICC was 0.80, 0.75 and 0.78 respectively. Intra-observer reliability of CD on CR, CT and MRI respectively had an intra-class correlation coefficient (ICC) minimum and maximum of 0.71-0.84, 0.67-0.83, 0.26-0.84. For inter-observer reliability the ICC was 0.76, 0.72 and 0.41 respectively. The PTI shows good intra- and inter-observer reliability, respectively with ICC minimum and maximum of 0.81-0.91 and ICC 0.80. According to the results of this study, the IS has the highest intra- and inter-observer reliability on CR and the PTI has the highest intra- and inter-observer reliability on MRI.

Apart from measurement reliability, other relevant measurement characteristics are validity, responsiveness and interpretability. Validity is defined as the degree to which an instrument truly measures the construct it purports to measure[1]. The clinical relevance of patella alta is that the patella engages later in flexion in the trochlear groove and therefore has a longer course of potential instability. A valid measurement of patellar height should therefore measure the height of the patella relative to the trochlear groove. None of the measurements on CR in this study use the trochlear groove as reference point. Only the PTI references patellar height to the trochlear groove. One disadvantage of this MRI-measurement is that MRI scanning is done with the knee in a knee coil in approximately 15-20 degrees

of flexion, in which situation the patella normally already has entered the trochlear groove. A second disadvantage of the PTI is that patellar height can be influenced by trochlear dysplasia.

Responsiveness is the ability of an instrument to detect change over time in the construct to be measured[1]. This is problematic for pre- and postoperative measurement after tibial tubercle distalization using the IS or MIS. These measurement methods measure distance from the patella to the tibial tuberosity, this distance is not changed with tibial tubercle distalization and is therefore not responsive.

All of the currently available measurement methods have inherent shortcomings in measurement characteristics such as reliability, validity and responsiveness. As briefly described above: there is no perfect measurement conceivable. A combination of two measurements might provide the best of both worlds. We would propose to measure patellar height on CR using CD in combination with the PTI on MRI. The CD can be used to screen for patella alta on CR, has a reliability very close to IS and has the advantage of responsiveness on tibial tubercle distalization. When surgery is considered, additional MRI could be performed to be able to measure the PTI, which also has a high reliability and uses the femur as reference point, which might be a more valid and clinically relevant reference point and could be used to guide the decision on whether to perform distalization or not. For determining the amount of distalization, the PTI could also be taken into account, aiming for a PTI between 12.5 and 50%. The surgeon can further specify the goal for an individual patient based on patient specific anatomy.

Next to the measurement characteristics, the accuracy of imaging is influenced by various variables which affect the quality of imaging and the reliability of measurements. Awareness of these limitations is essential in interpreting the results of conventional radiograph based measurements, and translating these measurements into decision making tools for preoperative planning in daily practice. A possible limitation of our study is that most conventional radiographs were not perfect lateral views, which decreases uniformity in position of the knee. Koëter et al. demonstrated the importance of position of the X-ray tube, they found that a radiograph in 5 degrees rotation can result in false measurements[2].

Historically, CT and MRI are performed with the patient supine, on CT with the knees in neutral position and on MRI with the knees in approximately 20 degrees of flexion in a coil. There is often heterogeneity between imaging protocols between hospitals. With the patient supine and the knee in neutral position, there is no dynamic stabilization of the patella and the position is dependent on leg axis (or position) and static anatomic stabilizers. Kaiser et al. demonstrated that in this position patellar tilt and patellofemoral axial engagement are determined by type of trochlear dysplasia, knee torsion and tibial tubercle-trochlear groove distance (TT-TG), all static anatomical factors[3]. However, dynamic stabilization can play an

important role in patellofemoral (in)stability. It could be argued that the currently performed static CT or MRI measurements (with heterogeneity in position) are not representative for the functional and dynamic problem of the patient.

Next to static nature of the current imaging methods, a limitation of the currently used measurements is that they are performed on two-dimensional imaging. Nha et al.[4] demonstrated a new method of measurement of TT-TG based on a three-dimensional (3D) CT image modeling and showed lower measurement bias and improved reliability for the measurement of TT-TG in patients with femoral trochlear dysplasia. This might only be the beginning of a reset of measurement methods and normal values with increased reliability and validity, now based on three-dimensional imaging.

The previously described issues stress the importance of a strict protocol for imaging in patients with patellofemoral instability to increase uniformity, reliability and validity of the measurements. The importance of alignment has been outlined previously. An optimal and uniform alignment should be the desired goal. This might be checked by 3D techniques such as are already in use for navigated surgery.

A future imaging protocol could include CR, 4D CT and MRI. We propose that the position of the patient in a scan should be supine, with patellae facing forward, knees in 10° flexion, no hip abduction or adduction. For 4D scanning, then the first movement is from 90° to full extension by active range of motion against a resistance of ½ body weight. Then, under eccentric quadriceps force let the weight rebound until 100° flexion.

A suggestion for which techniques and measurements a future imaging protocol for patients with patellofemoral instability could include is presented on this page:

- Conventional radiography
    - Standing posterior-anterior fixed flexion view and standing true lateral knee, both in 10° flexion
    - Patellar height: Caton-Deschamps
    - Trochlear dysplasia: differentiate between normal trochlea (no crossing sign, no bump), low-grade (only crossing sign, Dejour type A) and high-grade (crossing sign and bump or double contour sign, Dejour type B, C and D) trochlear dysplasia
- 4D CT
    - Standardized alignment, checked by 3D referencing
    - Active weight-bearing range of motion
    - Patellar tracking
    - 3D measurement lateralization

- MRI
    - Patient supine with knee in 10° flexion
    - 3D morphology of trochlea
    - PTI and 3D measurement patellar height
    - 3D measurement lateralization

Tibial tubercle osteotomy

Research questions:

1. *What is the incidence of postoperative complications, specifically fracture and non-union, after a self-centering tibial tubercle osteotomy? (Chapter 3)*
2. *What is the incidence of postoperative complications, specifically fracture and non-union, after a V-shaped tibial tubercle osteotomy? (Chapter 4)*

In Chapter 3 and Chapter 4 the risk of procedure specific postoperative complications of respectively the self-centering sliding tibial tubercle osteotomy (TTO) and V-shaped TTO are quantified. In Chapter 3 the results and complications in a large case series (447 patients, 529 knees) on the self-centering sliding TTO are presented. Major complications related to the osteotomy were reported in 9 cases (1.7%). These include 3 patients with a non-union and two patients with a fracture of the tibia/tibial tubercle during follow-up both at the site of previous realignment surgery.

In Chapter 4 the study on the rate of complications after a V-shaped TTO is presented, this study includes 263 knees in 203 patients. Major complications occurred in 13 knees (4.9%). Two patients sustained a tibial shaft fracture. In two cases, there was a problem with the part of bone that was replaced proximally after removal from the distal side of the osteotomy, needing further surgery. There was one patient with a septic arthritis and one patient with a non-union. In three patients, proximalization of the tibial tubercle without screw breakage was seen.

The main weakness of both of these studies is the retrospective design. All currently available patient records were reviewed; however, a few cases might be lost due to registration bias. Both of the studies were performed in hospitals with a specialized character of clinical practice on patellofemoral instability. This focus has led to a good administration of surgical treatment and follow-up of these patients. This has also led to the distinct advantages of these studies such as the large sample size with a uniform technique of TTO and protocolized postoperative care.

As outlined in the introduction of this thesis, the occurrence of major osteotomy specific complications after a TTO might be related to the technique that is performed[5]. Nonunion and fracture are two complications that could be related to surgical technique and postoperative care. The studies in chapter 3 and 4 do not answer the question on how these different techniques affect blood supply and biomechanical strength. It does answer the final outcome in terms of rates of nonunion and postoperative fracture. Both techniques have a low rate of nonunion (maximum 0.6%) and postoperative fracture (maximum 0.8%). For the self-centering sliding TTO it is essential to maintain the blood supply from the medial periosteum. The V-shaped TTO receives enough endosteal blood supply due to the large contact area of trabecular bone that is created. We conclude that both techniques are safe techniques with a low rate of nonunion and fracture. The decision on which technique to perform could be based on the goal of the osteotomy (medializing and/or distalizing). When only distalization is required, both the self-centering sliding TTO and the V-shaped TTO are good options. The self-centering TTO has the advantage of centering the patella, which is inherently part of the technique. When additional or only medialization is required, the self-centering sliding TTO is the preferred technique.

Trochleoplasty

Research questions:

1. *What is the effect of age on patient reported outcome after a lateral facet elevating trochlear osteotomy? (Chapter 5)*
2. *Do the clinical and radiological results of a lateral facet elevating trochlear osteotomy deteriorate in patients with a minimum of 12 year follow-up? (Chapter 6)*
3. *What is the rate of complications after various techniques used for trochleoplasty? (Chapter 7)*

In Chapter 5 of this thesis, we analyzed the effect of age on the patient reported outcome of a lateral facet elevating trochlear osteotomy. The outcome of 125 surgical procedures was evaluated. In our cohort of patients with a mean age of 19.8 years (range 12.5-46.3) at surgery, multivariable regression analysis revealed a correlation between age at time of surgery and VAS pain at rest. The clinical relevance of the small increase is doubtful. Age at time of surgery did not have a significant effect on the other outcome measurements. The mean KKS in our study was 73, which is acceptable in our opinion.

A notable result of this study was the rate of patella redislocation (13 patients, 10%). These patients were relatively young. The average age of these patients with

recurrent dislocation was 16 years, the average age of the cohort was 19.8 years. It should be mentioned that the absolute number (13 dislocations) is small and the difference in mean age is not statistically significant.

A contributing factor for this rate of dislocation is the absence of an additional MPFL-reconstruction, this was only performed in 5.6% of patients. A methodological limitation of this study is the heterogeneity of the study population. One should be aware of this when interpreting these results and translating these to daily practice.

In Chapter 6 we established the long-term results of the lateral facet elevating trochlear osteotomy. We re-evaluated a cohort of 17 patients to describe the clinical and radiological results over time of this technique in patients at a minimum of twelve years after surgery. Follow-up of this cohort could be obtained in 12 patients and 15 knees with a mean follow-up of 14.3 years. Mean age at follow-up was 36.5 years. Late complications, subsequent surgery, number of recurrent dislocations, VAS pain, Lysholm, WOMAC and Kujala Knee scores were obtained. Physical examination was performed and conventional radiographs were taken. Patient reported outcome scores showed no significant deterioration from 2 years to final follow-up. Four patients reported a recurrent patellar dislocation. We observed an increase in radiological osteoarthritis in all three compartments of the knee (medial tibiofemoral, lateral tibiofemoral, patellofemoral) when compared to pre-operative values, but this increase was limited to the lower grades on Kellgren Lawrence[6] and Iwano scale[7].

Chapter 5 and Chapter 6 both present outcomes after a lateral facet elevating trochlear osteotomy. The indication for this type of trochlear osteotomy has narrowed in recent years and consequently the procedure is performed less often. Therefore, it might be even more important to have data on previous outcome of this procedure. The results of the study presented in chapter 6 do not confirm the concern for early patellofemoral osteoarthritis (PF OA) after this procedure that exists among many physicians. In both studies an additional MPFL-reconstruction was rarely performed, which might have led to a relatively high rate of redislocation.

Strict indication for this type of trochlear osteotomy is key to a satisfactory result. Patients with recurrent patellar dislocation with a prominent J-sign at physical examination (indicating clinically relevant maltracking at early flexion) and underlying trochlear dysplasia without a proximal bump but with a convex or short proximal trochlea can be a good candidate for a lateral facet elevating trochlear osteotomy. A medial patellofemoral ligament (MPFL) reconstruction should always be performed as additional procedure to decrease the risk of recurrent dislocation. With these considerations in mind, a lateral-facet elevating trochlear osteotomy is a safe procedure with a satisfactory result.

Chapter 7 presents the results of a systematic review of literature and meta-analysis to assess the rate of complications after various techniques used for trochleoplasty. The search strategy retrieved 1,848 unique records. The subsequent selection procedure resulted in 20 studies which could be included in the systematic review. These studies included 822 trochlear osteotomy procedures in 739 patients with an average age of 22.6 years. A total of 190 complications occurred including recurrent instability, loss of knee range of motion, development or progression of PF OA and return to the operating room. Meta-analysis was performed for the following complications: recurrence of patellar instability, recurrent dislocation, patellofemoral osteoarthritis and further surgery for Bereiter- and Dejour-type trochleoplasty procedures. The Bereiter and Dejour trochleoplasties showed complication rates similar to other patellar stabilizing procedures. The proportions of reoperation were 0.08 and 0.20 respectively. Decreased range of motion and recurrence of instability were the two most frequent reasons for further surgery. The proportion of redislocation was 0.04 and 0.02 respectively, which is relatively low. The results of this study indicate that these two trochleoplasty techniques successfully prevent recurrent dislocation and/or instability and have a rate of complications similar to other patellar stabilizing procedures.

Almost all studies included in this systematic review and meta-analysis were retrospective or prospective case series. None of the studies were randomized or were comparative studies. Therefore, no conclusion can be drawn as to whether one of the techniques of trochleoplasty is superior to the other in terms of rate of complications.

Surgical treatment of patients with recurrent patellar instability is still a challenging and controversial subject. The corner stone of surgical treatment is reconstruction of the MPFL. Results of the studies presented in Chapter 3-7 indicate that both a tibial tubercle osteotomy (TTO) and a trochleoplasty can be a safe part of the surgical treatment plan. However, based on our studies no conclusions can be drawn on when to perform which type of osteotomy with how much correction. Rood et al.[8], proposed an algorithm in which a trochleoplasty is indicated in patients with high grade trochlear dysplasia and a TTO is indicated in case of patella alta or excessive lateralization. However, there is still a need for improvement of (and more nuance on) indication of these type of osteotomies.

Outcome measurement

Research questions:

1. *Are the translated Banff Patellar Instability Instrument and Norwich Patellar Instability score valid patient reported outcome measurements? (Chapter 8)*

In Chapter 8 the Banff Patellar Instability Instrument (BPII) and Norwich Patellar Instability score (NPI) were translated and validated in Dutch to fill in the lack of Dutch PROMs on patellofemoral disorders. These are two patient reported outcome measurements (PROMs) specifically designed for patients with patellofemoral disorders. The translation of the scores followed the MAPI method[9]. Clarity, understandability and acceptability was evaluated in a pilot series of 15 patients. Ninety-seven patients that had been surgically treated for patellofemoral instability completed all questionnaires. The internal consistency of the BPII and the NPI was excellent. Both scores demonstrated good reliability. The results of this study indicate that the Dutch version of the BPII and the NPI can be used for patients with patellofemoral instability.

Treatment of patients with patellofemoral instability aims to improve patellar tracking leading to a stable patella that does not dislocate and with that to decrease functional impairment and pain due to patellar instability. The outcome of treatment can be objectified by recurrence of patellar dislocation. This outcome parameter is often described in studies reporting on conservative and/or surgical treatment of patients with patellofemoral instability. However, it is clear that focusing on these 'objective' outcomes neglects the 'subjective' outcome experienced by the patient. This subjective outcome can be measured by valid and reliable disease specific patient reported outcome measurements (PROMS). The translation and validation of the PROMs which are specifically designed for patients with patellofemoral instability can be a starting point to get a better view on 'subjective' outcome and the correlation with the 'objective' outcome. We advise that they should be included in the routine measurement of outcome of treatment of patients with patellofemoral instability.

The indication for surgical treatment of patellofemoral instability is often a combination of objective characteristics and subjective complaints. So far, most of the studies on patients with patellofemoral instability have used objective outcomes or general PROMs that might not be reliable measurements because patients are asked about general knee complaints and not specifically patellofemoral complaints. Consequently, these scores underestimate the impact of patellofemoral instability complaints on daily life of patients. Better understanding the perceived disability, can help to decide whether surgical treatment is indicated in an individual patient and can be used to predict outcomes for better management of patient expectations.

Future perspectives

In the introduction and general discussion of this thesis, we described the multifactorial character of treatment of patients with patellofemoral instability. Current imaging techniques and measurements, treatment algorithms and outcome measurements are under continuous development. It is therefore a very

dynamic field of research with a lot of opportunities to further optimize treatment for these patients. Some future opportunities for optimalization of treatment of patients with patellofemoral instability will be proposed in the next paragraphs and we will propose a workup of patients with patellofemoral instability based on the answers on the research questions, the discussion and future perspectives of this thesis.

Future perspectives on imaging

Future opportunities for protocolized imaging and measurements in patients with patellofemoral instability might be found in four-dimensional (4D) scanning. In addition to 3D reconstructed CT- or MR-scanning, 4D means that a controlled movement in one plane is performed and registered during the scan. Using software, a 3D reconstruction of the leg and the movement can be reconstructed and display the important anatomic structures during the performed arc of motion. Rather than scanning during non-weightbearing knee motion, scanning during active range of motion against resistance might be performed. That could demonstrate the tracking of the patella while both static and dynamic stabilizers are active. This could give new data on how the known anatomic risk factors change during range of motion with active dynamic stabilization. It would also provide normal values for these risk factors on 3D and 4D CT-scanning which might be a better representation of relevant abnormal anatomy than the normal values that are currently based on two-dimensional imaging.

Another opportunity for 4D CT-scanning is to model the 3D anatomy and movement of a patient and then alter the anatomy using computer software. This will be further worked out in the next section on indications for osteotomies.

Future perspectives on indications for osteotomies for patellofemoral instability

Improving the workup and consequently the indications for osteotomies for patellofemoral instability, by being able to simulate the surgical correction might be the key to improvement of (patient reported) outcome. Simulating patellar tracking with correction for relevant anatomic risk factors for a specific patient in one model that includes dynamic factors, creates the possibility for modification of these risk factors to an optimum. In contrast to the current practice of determining amount of correction on different static imaging methods.

To accomplish a better workup, a digital decision tool for orthopaedic surgeons specialized in treating patients with patellofemoral instability can be developed in the future. For the best outcome, the orthopaedic surgeon needs to collect the right ingredients during the workup. These include both demographic factors and

patient specific anatomic static and dynamic risk factors for recurrent patellar instability. Demographic risk factors that should be registered are age at first dislocation, sex, uni- or bilateral dislocations, Beighton score and BMI [10-13]. The anatomical and biomechanical risk factors should be mapped by a standardized protocol for physical exam, imaging techniques and radiologic measurements. A computational simulated adaption of patellofemoral anatomy and patellar tracking could then be made combining 4D CT and MR images. A validated model of this simulation could be developed in which the anatomy of a specific patient with patellar dislocation or maltracking can be altered to reconstruct the tracking of the patella to a patient specific optimal reconstruction. In this simulation the orthopaedic surgeon can adapt patellofemoral anatomy step by step. First, reconstruction of the MPFL is simulated leading to a new simulation of patellar tracking. Then, lateralization and patellar height can be adapted if necessary. Last, trochlear morphology can be adapted and consequently simulate the new patellar tracking pattern after a TTO and trochleoplasty. By this simulation, one can make an individualized surgical treatment plan including the decision if an osteotomy is indicated. Anatomic risk factors such as rotational deformities and coronal plane malalignment could be taken into account on indication by the surgeon as well as dynamic risk factors that have been assessed during physical exam.

A tibial tubercle osteotomy could be indicated for persistent lateral tracking (medializing TTO) and/or late engagement of the patella in the trochlear groove (distalizing TTO) despite simulated MPFL-reconstruction. A trochleoplasty could be indicated for persistent lateral tracking or tracking over a trochlear bump despite MPFL-reconstruction and TTO. A deepening trochleoplasty is indicated in patients with a trochlear bump. A lateral facet elevating trochlear osteotomy could be indicated in patients with persistent lateral tracking without a bump but with a convex or short proximal trochlea. If an osteotomy is indicated, a proposed amount of correction of trochlear morphology, patellar height or lateralization can be given.

Also at every step demographic and dynamic risk factors can be taken into account to decide whether to perform additional procedures or not. When demographic and dynamic risk factors predict worse outcome after isolated MPFL-reconstruction a TTO can be indicated to increase chance of a good outcome when there is more lateralization or a higher patella than average, despite the threshold value which is normally used is not reached.

Step by step the surgeon can build a final proposal for a treatment plan for an individual patient which can then be discussed, including management of expectations.

Advances in imaging and more accurate preoperative planning could result in a patient specific treatment plan. Next, it is essential to be able to accurately verify the planned amount of correction intra-operatively. A prerequisite for accurate

measurements is a thorough knowledge on normal and abnormal patellofemoral anatomy, physiology, pathophysiology and surgical treatment. Therefore, we advise that only surgeons educated or experienced in patellofemoral surgery should perform these type of operations. With the right education and experience, intra operative measurement of distance (often in terms of millimeters) in the right plane and direction combined with intra-operative testing for stability, is still the most accurate and reliable verification method to assess if the amount of correction that is achieved is correct so far. The surgeon has to take the lack of dynamic stabilization intra-operatively into account. However, in the future, 3D navigated and controlled surgical instrumentation and patient specific instrumentation can probably improve intra-operative measurement of correction which has been planned using software including dynamic stabilization.

Future perspectives on outcome measurement

To improve our understanding of perceived disability by patients with patellofemoral instability, a multicenter study in which patients are urged to fill out these patellar instability specific PROMs at first consultation and then consequently at follow-up, independent of nonoperative or operative treatment is expedient. This will increase our understanding of the natural course of impact on daily living and quality of life of patellofemoral instability, something we still do not completely understand. A majority of patients are seen first by an orthopedic surgeon at adolescence. The expected impact on their future quality of life is hard to predict and decision making is partly based on personal experience of the surgeon. However, those patients are at an age that they have to make critical choices for the rest of their life and are looking for a more specific answer on the question of the natural course of impact of these complaints. A large epidemiological study in cooperation with general physicians (GP's) could possibly increase our knowledge on the natural course of impact on quality of life of patellofemoral instability.

The future perspectives outlined above illustrate that there are numerous opportunities to optimize the multidimensional treatment of patients with patellofemoral instability. It also illustrates that there is still a research and knowledge gap. Some future research topics that could be explored include:

- Assessment and validation of normal values for 4D CT-scanning in normal knees and in knees of patients with patellofemoral instability and trochlear dysplasia.
- Which (maybe a new) measurement for lateralization is the optimal for use on 4D CT-scanning?
- Validation and assessment of accuracy and clinical relevance of computer simulation based on 4D CT-scanning.

- Epidemiology and natural course of impact on quality of life for non-operative treatment of patellofemoral instability.
- What is the additional value of a surgical treatment decision tool?

Based on the current knowledge and topics discussed in this thesis we propose a schematic treatment flowchart for patients with recurrent patellofemoral instability for whom surgical treatment is considered (figure 1). The goal of this workup is to select the most optimal surgical treatment for every individual patient for who surgery is indicated. In the workup, we advise to implement a standardized radiological workup, as outlined in the discussion on 'imaging'. The data that is collected during workup, is the input for a decision tool that includes dynamic imaging and computational simulations of patellar tracking. This tool can guide the choice for which surgical procedures to perform. Future opportunities to optimize measurement of correction during surgery should be sought for and implemented when available, for example patient specific instrumentation or 3D-navigation assisted surgery. Outcome of surgery should be measured by objective measurements as well as subjective patient reported outcome measurements.

The scheme illustrates that the key to a satisfiable outcome is a complete diagnostic workup and a well-considered decision, ultimately aided by a decision tool that includes all available clinical and scientifical information and is able to simulate patellar tracking after adaption of patient specific anatomy.

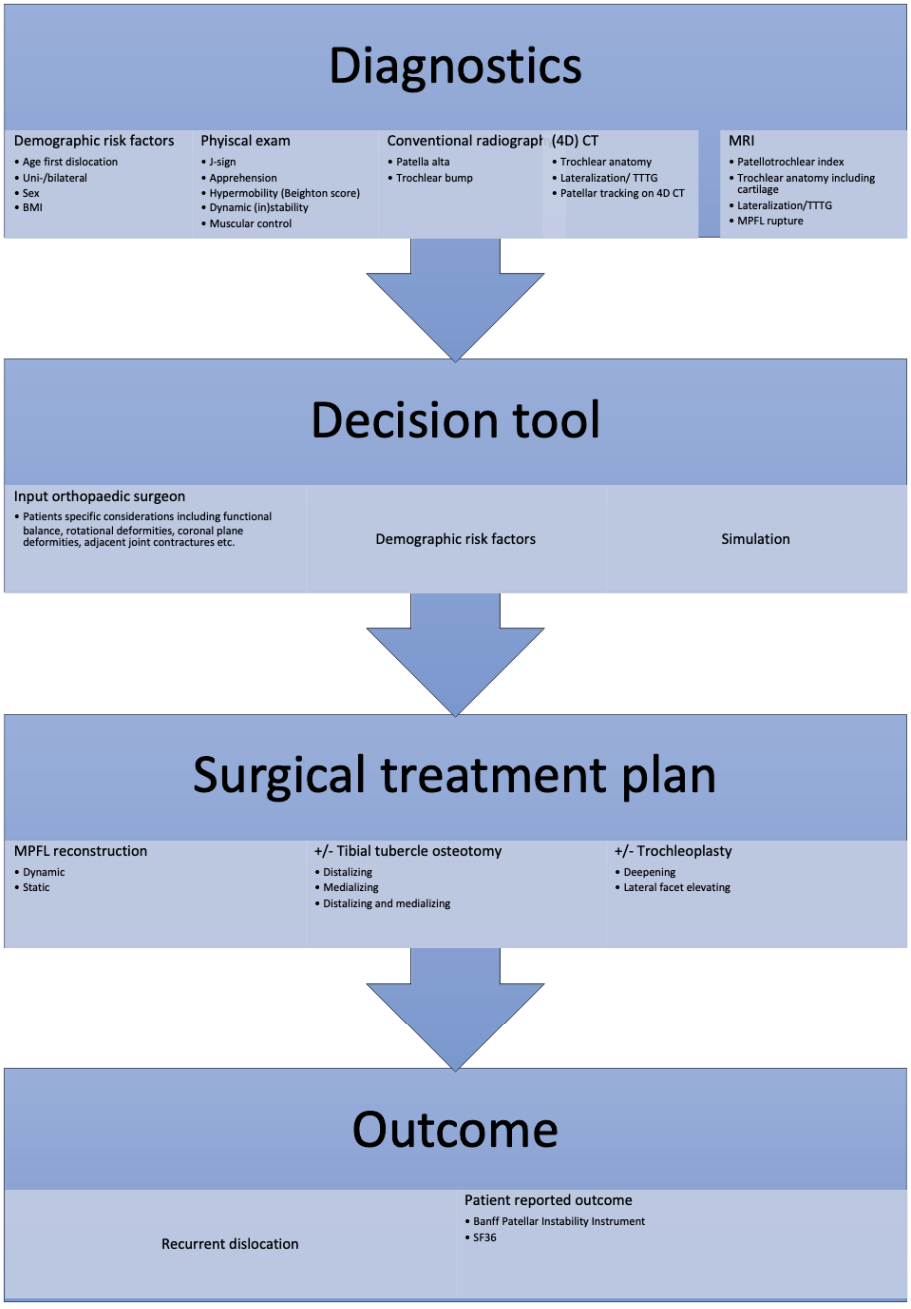


Figure 1. Schematic flowchart for patients with recurrent patellofemoral instability for whom surgical treatment is considered.

Conclusions

The answers on the research questions and the general discussion of this thesis lead to the following conclusions:

1. The current radiologic measurement methods for patellar height are reliable, but there is no single perfect measurement, all have their shortcomings. We propose to measure patellar height on conventional radiographs using Caton-Deschamps. One should be aware of the shortcomings of measurements of patellar height, lateralization and trochlear dysplasia when interpreting results and deciding on which surgical treatment to perform.
2. The rate of major complications of tibial tubercle and trochlear osteotomies for the treatment of patellofemoral instability is low and these procedures can be considered safe.
3. Two patellofemoral instability specific patient reported outcome measurements have been translated to Dutch and validated in a Dutch population and can now be used to measure subjective outcome of patients with patellofemoral instability and/or pain.

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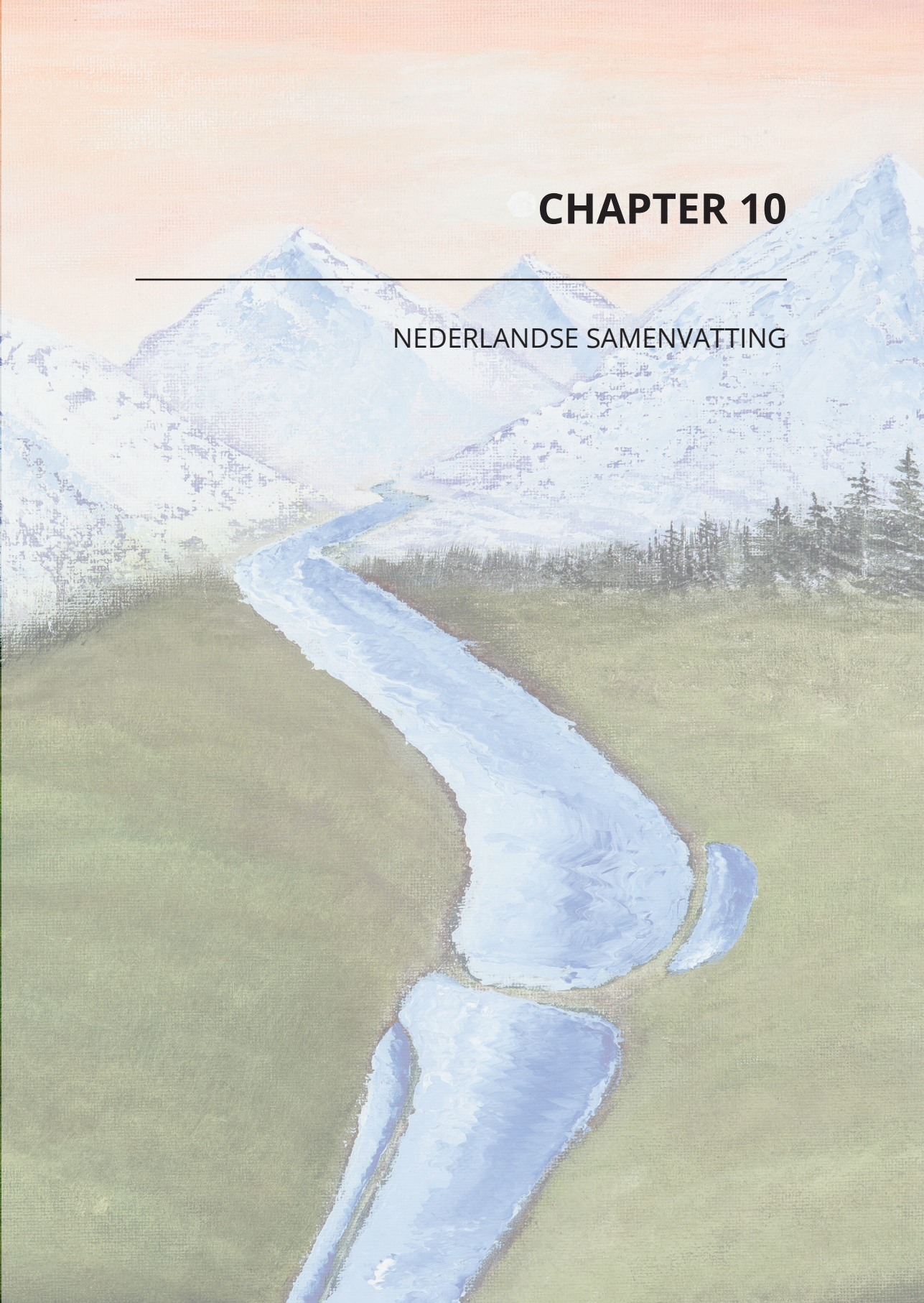


CHAPTER 10

NEDERLANDSE SAMENVATTING

Samenvatting

In de introductie van dit proefschrift is het multidimensionale karakter van de behandeling van patiënten met patellofemorale instabiliteit uiteengezet. Het doel van dit proefschrift was het optimaliseren van de behandeling van patiënten met patellofemorale instabiliteit door het uitbreiden van de wetenschappelijke kennis over relevante aspecten van de behandeling.

In Hoofdstuk 2 is de betrouwbaarheid (reliability) van patellahoogte metingen onderzocht. Voor de Insall-Salvati ratio (IS), de Blackburn-Peel ratio (BP), Caton-Deschamps ratio (CD) en de modified Insall-Salvati ratio (MIS) zijn op conventionele röntgenfoto's, CT-scans en MRI-scans de intra- en interrater-reliability onderzocht. De intra-rater reliability is de accuraatheid van dezelfde meting van één onderzoeker op verschillende meetmomenten. De interrater reliability is de accuraatheid van een bepaalde meting tussen verschillende onderzoekers. De patellotrochlear index (PTI) is een meting die alleen op MRI uitgevoerd kan worden en is dus alleen op MRI gemeten.

De IS had de hoogste intra- en interrater-reliability op alle verschillende vormen van beeldvorming vergeleken met de BP, CD en MIS. De PTI gemeten op een MRI is even betrouwbaar als de IS.

Naast de betrouwbaarheid van metingen, zijn validiteit, responsiviteit en interpreteerbaarheid belangrijke eigenschappen van een meetinstrument. Alle bovengenoemde metingen hebben tekortkomingen op één of meer van deze domeinen en er is dan ook niet één optimale meetmethode. Een belangrijk nadeel van de IS is dat deze niet verandert bij een tuberositas distalisatie, daarom is deze meting niet responsief. Wij stellen voor om in de dagelijkse praktijk patellahoogte te meten middels de Caton-Deschamps ratio op conventionele röntgenfoto's, eventueel in aanvulling met de Patellotrochlear index op MRI. De betrouwbaarheid van de CD is bijna net zo hoog als die van de IS en de CD is wel responsief.

Behalve de meetinstrumenten, wordt de accuratesse van metingen beïnvloed door bijvoorbeeld de kwaliteit van apparatuur en de positie van apparatuur ten opzichte van de patiënt en de houding van de patiënt. Inherente beperkingen van deze metingen zijn het tweedimensionale en het statische karakter. Daardoor zijn de beelden een versimpelde weergave van de driedimensionale anatomie van het dynamische probleem van patiënten. Radiologische onderzoeken zouden in de toekomst verbeterd kunnen worden als er uitbreiding komt van de kennis over dynamische beeldvorming en metingen op driedimensionale beelden. Tot het zo ver is, adviseren we een strikt protocol voor beeldvorming bij patiënten met patellofemorale instabiliteit om de uniformiteit, betrouwbaarheid en validiteit te optimaliseren. Dit protocol is uiteengezet in de discussie van het proefschrift.

Hoofdstuk 3 en hoofdstuk 4 presenteren de resultaten van ons onderzoek naar complicaties van respectievelijk de zelf-centrerende tuberositas osteotomie en de V-vormige tuberositas osteotomie. Het percentage ernstige complicaties (fractuur, pseudoartrose) direct gerelateerd aan de chirurgische procedure in een cohort van 447 patiënten met 529 operaties was 1,7% voor de zelf-centrerende tuberositas osteotomie. Drie patiënten ontwikkelden een pseudoartrose, bij twee patiënten ontstond een fractuur. Voor de V-vormige tuberositas osteotomie was het percentage ernstige complicaties 2,0% in een cohort van 203 patiënten en 263 operaties. Bij twee patiënten ontstond een fractuur in het postoperatieve beloop en één patiënt ontwikkelde een pseudoartrose.

Beide technieken van tuberositas osteotomie hebben dus een laag risico op de ernstige complicaties zoals pseudoartrose (maximaal 0,6%) of fractuur (maximaal 0,8%). We concluderen dan ook dat beide technieken veilig zijn met betrekking tot het risico op deze complicaties en geen van deze technieken superieur is ten opzichte van de ander vanwege het complicatierisico. De keuze voor het type techniek kan gebaseerd worden op het doel van de operatie. Als er alleen een tuberositas distalisatie nodig is, zijn beide technieken goede opties. Als er ook (of alleen) een indicatie is voor tuberositas medialisatie heeft de zelf-centrerende techniek de voorkeur.

Hoofdstuk 5 presenteert de resultaten van onderzoek naar de leeftijd ten tijde van de operatie (een laterale facet ophogende trochlea osteotomie) en de correlatie daarvan met patiënt gerapporteerde uitkomsten in een cohort van 113 patiënten met 125 operatieve procedures. Multivariabele regressieanalyse toonde een correlatie tussen hogere leeftijd ten tijde van de operatie met pijn in rust bij een gemiddelde follow-up van 6 jaar. De klinische relevantie van het verschil in pijnscore lijkt echter beperkt. Leeftijd ten tijde van operatie had geen correlatie met andere uitkomstmaten.

In Hoofdstuk 6 zijn de resultaten van de laterale facet ophogende trochlea osteotomie op lange termijn onderzocht. Er vond een herevaluatie plaats van een cohort van 17 patiënten met een minimale follow-up van 12 jaar, de gemiddelde follow-up duur was 14,3 jaar. De door de patiënt gerapporteerde uitkomstmaten waren niet verslechterd ten opzichte van 2 jaar na de operatie. Vier patiënten hadden een re-luxatie van de patella. Op de röntgenfoto's werd een toename van kenmerken van patellofemorale en tibiofemorale artrose gevonden, maar dit was beperkt tot de lagere gradaties op de Iwano- en Kellgren Lawrence-schaal.

Door ontwikkelingen in de ligamentaire chirurgie en de opkomst van andere type trochlea osteotomieën is de indicatie voor de laterale facet ophogende trochlea osteotomie de laatste jaren beperkter geworden. Patiënten met recidiverende patellaluxaties met onderliggend trochleadysplasie zonder bump, maar met een convexe en korte proximale trochlea, kunnen geschikte kandidaten zijn voor deze operatie. Aangevuld met een mediaal patellofemoraal ligament (MPFL)-

reconstructie ter voorkoming van recidief luxaties is deze operatie een veilige techniek met een goede patiënt gerapporteerde uitkomst.

De resultaten van een systematisch literatuuronderzoek naar en meta-analyse van complicaties na trochlea osteotomieën worden gepresenteerd in Hoofdstuk 7. Twintig studies met een totaal van 822 trochlea osteotomieën zijn geïncludeerd in dit onderzoek. De meest voorkomende complicaties waren re-luxatie, verminderde bewegingsuitslag van de knie, patellofemorale artrose en re-operatie, in totaal waren er 190 gerapporteerde complicaties. Er werd een meta-analyse verricht naar het verschil in optreden van re-luxatie, terugkerend gevoel van instabiliteit, patellofemorale artrose en re-operatie tussen de techniek volgens Dejour en die volgens Bereiter. Er was geen significant verschil in complicaties tussen deze twee technieken. Beide technieken leidden tot een lage kans op re-luxatie (Dejour 0,02 en Bereiter 0,04) met een mate van complicaties vergelijkbaar met andere patellofemorale chirurgie.

De onderzoeken uit Hoofdstuk 3-7 tonen aan dat zowel een tuberositas osteotomie als een trochlea osteotomie veilige onderdelen zijn van een chirurgisch behandelplan voor patiënten met patellofemorale klachten. In geval van patella instabiliteit wordt dit gecombineerd met een MPFL-reconstructie.

Tot voor kort ontbraken Nederlandstalige gevalideerde patiënt gerapporteerde uitkomstmetingen (PROMs) voor patiënten met patellofemorale klachten. Hoofdstuk 8 presenteert de vertaling naar het Nederlands en de daaropvolgende validatie in een Nederlandse populatie van de Banff Patellar Instability Instrument (BPII) en de Norwich Patellar Instability score (NPI). Dit zijn twee Engelstalige PROMs specifiek voor patiënten met patellofemorale klachten. De PROMs zijn volledig ingevuld door 97 patiënten. De interne consistentie van de BPII en de NPI was excellent en beide scores waren betrouwbaar. Deze twee vragenlijsten kunnen nu gebruikt worden voor patiënten met patellofemorale instabiliteit. Dit is van toegevoegde waarde bij het meten van de uitkomst van de (chirurgische) behandeling van patiënten met patellofemorale instabiliteit en het kan ons nieuw inzicht verschaffen in het door de patiënt ervaren effect van de behandeling. Op die manier kan het in de toekomst bijdragen aan gerichtere uitleg over verwachtingen en betere indicatiestelling.

De behandeling van en het onderzoek naar patellofemorale instabiliteit is multifactorieel en daarmee ook dynamisch met continu nieuwe ontwikkelingen en inzichten. Derhalve zal de behandeling van patellofemorale instabiliteit in de toekomst ook steeds verder geoptimaliseerd en vernieuwd blijven worden. Het toekomstperspectief voor verbetering van de radiologische beeldvorming bevat bijvoorbeeld 4D scannen. Hierbij voert de patiënt een gecontroleerde beweging in 1 vlak uit. Die beweging vindt dan plaats met of tegen een bepaalde belasting om op die manier een zo reëel mogelijke weergave van de functionele anatomie te verkrijgen, inclusief dynamische stabilisatie. Nieuwe metingen op

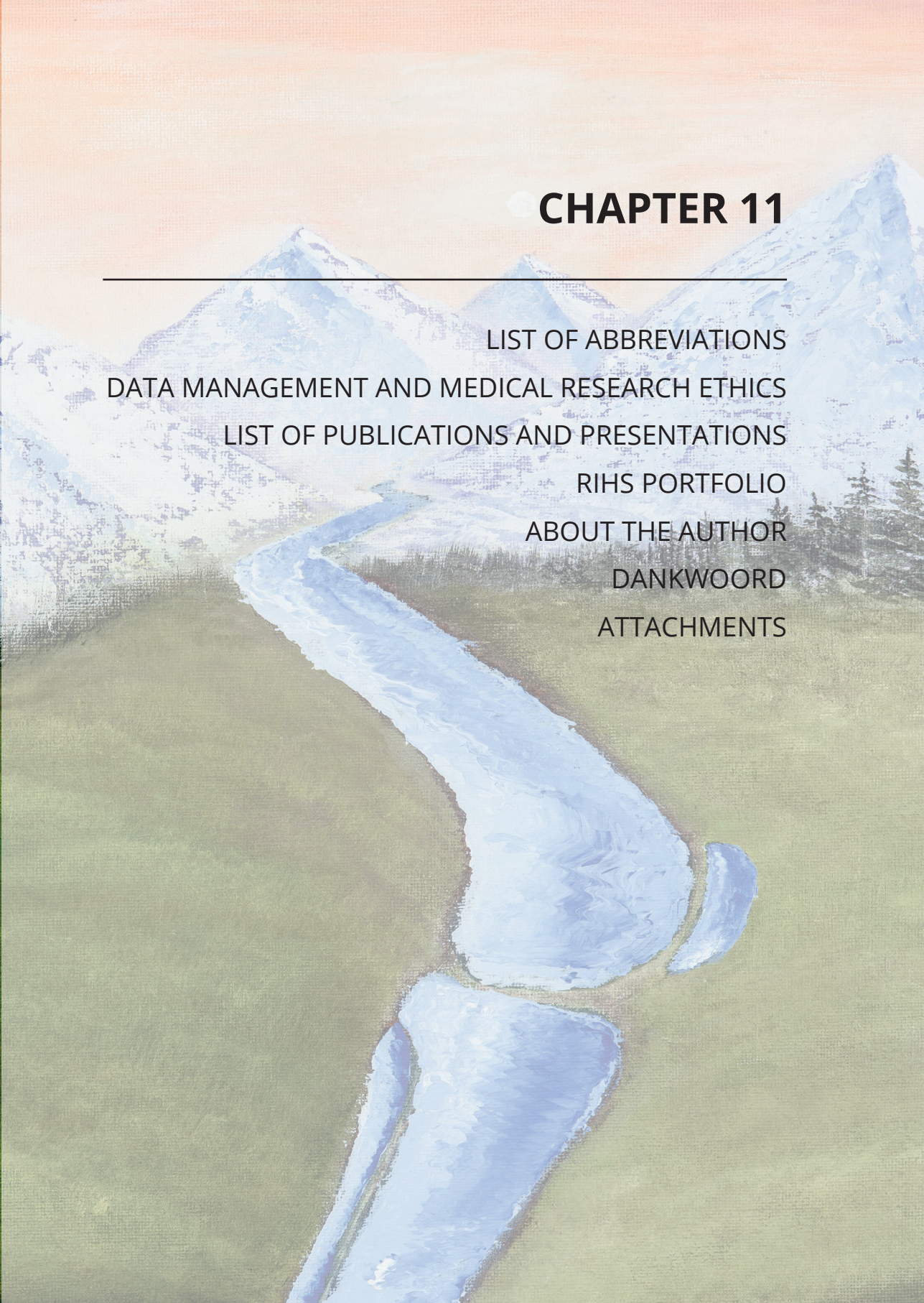
driedimensionale dynamische beeldvorming en nieuwe normaalwaardes voor bestaande metingen zullen dan ontwikkeld kunnen worden.

Het 4D beeld zou vervolgens in een computermodel verwerkt kunnen worden. Er kan dan gedacht worden aan het ontwikkelen van een computermodel waarbij de onderzoeker of de chirurg de anatomie van de patiënt stap voor stap kan aanpassen met chirurgische behandelopties totdat er een optimale patellasporing en stabiliteit is. Dat computermodel kan dan geïncludeerd worden in de volledige workup, waarvoor bijvoorbeeld een 'keuzehulp' ontwikkeld kan worden. Die zou alle demografische risicofactoren, patiënt specifieke anatomische risicofactoren en dynamische risicofactoren voor patella instabiliteit moeten bevatten. Die risicofactoren kunnen dan bij elke stap van het computermodel meegewogen worden bij de keuze voor het al dan niet toevoegen van een aanvullende chirurgische optie. Op die manier kunnen chirurg en patiënt samen tot een optimaal behandelplan komen met een goede inschatting van en voorlichting over het verwachte resultaat.

Conclusies

De antwoorden op de onderzoeksvragen en de daaropvolgende bespreking in de discussie van het proefschrift hebben tot de volgende conclusies geleid:

1. De huidige meetmethoden voor het meten van patellahoogte op radiologische beelden zijn betrouwbaar, maar elke meetmethode kent bepaalde beperkingen. We stellen voor om patellahoogte op conventionele röntgenfoto's te meten met de Caton-Deschamps ratio. Bij het interpreteren van de uitkomst en de keuze voor een behandeling is het belangrijk dat artsen zich bewust zijn van de beperkingen van het meten van patellahoogte, lateralisatie van de tuberositas en trochleadysplasie.
2. Het aantal ernstige complicaties na tuberositas osteotomieën en trochlea osteotomieëen is laag, deze chirurgische procedures kunnen als veilig beschouwd worden.
3. Twee patiënt gerapporteerde uitkomstmaten (PROMs) specifiek voor patellofemorale klachten zijn vertaald naar het Nederlands en gevalideerd in een Nederlandse populatie. Deze PROMs kunnen nu gebruikt worden bij het meten van de uitkomst van behandeling van patiënten met patellofemorale klachten.



CHAPTER 11

LIST OF ABBREVIATIONS

DATA MANAGEMENT AND MEDICAL RESEARCH ETHICS

LIST OF PUBLICATIONS AND PRESENTATIONS

RIHS PORTFOLIO

ABOUT THE AUTHOR

DANKWOORD

ATTACHMENTS

List of abbreviations

BP	Blackburne-Peel ratio
BPII	Banff patellar instability instrument
CD	Caton-Deschamps ratio
CI	Confidence interval
COSMIN	Consensus based standards for the selection of health measurement instruments
CPM	Continuous passive motion
CR	Conventional radiography
CT	Computational tomography
DVT	Deep venous thrombosis
FU	Follow-up
ICC	Intra-class correlation coefficient
IKDC	International knee documentation committee
IRB	Institutional review board
IS	Insall-Salvati ratio
KKS	Kujale knee score
K-L	Kellgren-Lawrence
KOOS	Knee disability and osteoarthritis outcome score
MIS	Modified Insall-Salvati ratio
MPFL	Medial patellofemoral ligament
MRI	Magnetic resonance imaging
NPI	Norwich patellar instability score
NRS	Numeric rating scale
OR	Operating room
PF	Patellofemoral
PF OA	Patellofemoral osteoarthritis
PROMs	Patient reported outcome measurements
PTI	Patellotrochlear index
OA	Osteoarthritis
ROM	Range of motion
SF-36	Short form 36-item health survey
TCP	Tricalcium phosphate
TKA	Total knee arthroplasty
TSA	Tubercle-sulcus angle

TTO	Tibial tubercle osteotomy
TT-MIELTI	Tibial tubercle – mid inter-epicondylar line trochlea intersection
TT-PCL	Tibial tubercle – posterior cruciate ligament distance
TT-TG	Tibial tubercle – trochlear groove distance
VAS	Visual analogue scale
VMO	Vastus medialis obliquus
VTE	Venous thrombo-embolism

Data management and medical research ethics

Data management

The data obtained during this PhD-project are stored in digital files on the local servers of Radboudumc and Canisius Wilhelmina Hospital (CWZ).

Published data generated or analyzed in this thesis are part of published articles and its additional files are available from the associated corresponding authors on request.

In order to protect the privacy of patients, data are anonymized and personal data were removed from the files. To ensure interpretability of the data, all filenames, primary and secondary data and scripts used to provide the final results are documented along with the data.

Using the patient data in future research is only possible when performed for health care improvement analyses. The datasets analyzed during these studies are available from the corresponding author on reasonable request.

Declaration of Helsinki

This thesis is based on the results of data analysis of patient files, which were conducted in accordance with the principles of the Declaration of Helsinki. The studies in this thesis have been conducted in order to analyze and improve provided clinical care. The studies described in Chapter 2 and 3 are retrospective studies performed in Canisius Wilhelmina Hospital (CWZ). For these studies there was a protocol approved by the Local Ethical Committee of CWZ.

The studies described in chapter 4 was a retrospective patient file study performed in Radboud University Medical Center. Data for study in chapter 5 were retrospectively collected in Radboudumc, Institutional Review Board approval was obtained for this study.

The study in chapter 6 was a prospective case series for which ethical approval was obtained, all patients gave informed consent.

For the study in chapter 8 patients who participated in previous retrospective studies in Radboudumc and CWZ were contacted. The Institutional Review Board of Radboudumc deemed that the Medical Research Involging Human Subject Act (WMO) did not apply.

List of publications and presentations

J.D.P. van Sambeeck, N. Verdonschot, A. van Kampen, S.A.W. van de Groes. Age at surgery is correlated with pain scores following trochlear osteotomy in lateral patellar instability; a cross-sectional study of 113 cases. *Journal of Orthopaedic Surgery and Research 16:337 (2021).*

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A. Rood, **J. van Sambeeck**, S. Koëter, A. van Kampen, S.A.W. van de Groes. A detaching, V-shaped tibial tubercle osteotomy is a safe procedure with a low complication rate. *Arch Orthop Trauma Surg 140(12):1867-1872 (2020)*

J.D.P. van Sambeeck, S.A.W. van de Groes, S. Koëter. Dutch translation and validation of the Norwich Patellar Instability score and Banff Patella Instability Instrument in patients after surgery for patellar instability. *Acta Orthopaedica Belgica 86(3):470-481 (2020*

F.V. Verhulst, **J.D.P. van Sambeeck**, G.S. Olthuis, J. van der Ree, S. Koëter. Patellar height measurements: Insall-Salvati ratio is most reliable method. *Knee Surg Sports Traumatol Arthrosc. 28, 869-875 (2020)*

J.D.P. van Sambeeck, S. Koëter. Diagnostiek en therapie bij patellofemorale instabiliteit, *Physios, 2018 (1): 36-43*

J.D.P. van Sambeeck, S.A.W. van de Groes, N. Verdonschot, G. Hannink. Trochleoplasty procedures show complication rates similar to other patellar-stabilizing procedures. *Knee Surg Sports Traumatol Arhtrosc. 26, 2841-2857 (2018)*

S. Tigchelaar, **J. van Sambeeck**, S. Koëter, A. van Kampen. A stand-alone lateral condyle-elevating trochlear osteotomy leads to high residual instability but no excessive increase in patellofemoral osteoarthritis at 12-year follow-up. *Knee Surg Sports Traumatol Arthrosc. 26(4):1216-1222 (2018)*

Abstract NOV Najaarscongres 2016. Titel: Leeftijd gerelateerde resultaten van trochlea osteotomie met een minimum van 5 jaar follow-up. Auteurs: **J.D.P. van Sambeeck**, S.A.W. van de Groes, A. van Kampen, N. Verdonschot.

Abstract NVA Jaarcongres 2016. Titel: Effect of age on the results of trochlear osteotomy at a minimum of 5 years follow-up. Auteurs: **J.D.P. van Sambeeck**, S.A.W. van de Groes.

W.R. Spanjersberg, **J.D.P. van Sambeeck**, A. Bremers, C. Rosman, C.J.H.M. van Laarhoven. Systematic review and meta-analysis for laparoscopic versus open colon surgery with or without an ERAS programme. *Surg Endosc (2015) 29:3443-3453.*

Abstract jaarlijkse conferentie Minnesota Orthopaedic Society 2013 St. Paul, Minnesota. Functional testing among high school athletes. Auteurs: **Jordy D.P. van Sambeeck**, Elizabeth A. Arendt, Julie Agel.

Jordy van Sambeeck, Elizabeth Arendt, Chris Rud. Jeffrey Macalena, Periosteal sleeve avulsion fracture of the quadriceps tendon. *Journal of Knee Surgery Reports 2016.*

Radboud Institute for Health Science PhD portfolio

Name PhD Cadidate: J.D.P. van Sambeeck
Department: Orthopaedic Surgery
Graduate School: Radboud Institute for Health Sciences
PhD period: 29-06-2015 – 31-05-2021
Promotor(s): Prof. dr. ir. N.J.J. Verdonschot
Co-promotor(s): Dr. ing. S.A.W. van de Groes
Dr. S. Koëter

	Year(s)	EC points
TRAINING ACTIVITIES		
Courses and Workshops		
- Masterclass patellofemorale instabiliteit, Nijmegen	2016	0.4
- WMO/Good Clinical Practice Course, Nijmegen	2018	0.8
- ROGOO educational program for orthopedic residents	2016-20	4
- Followed courses for orthopedic training (ATLS provider course, OTC II operatieve fractuurbehandeling, AO trauma course, NVA arthroscopiecursus knie, CCOC-courses (9x), cursus knieprothesiologie, NOV starterscursus voet/enkel, cursus heupprothesiologie, basiscursus osteotomie ViaSana, Stralingshygiëne voor medisch specialisten)	2017-20	17.5
- Resident days on trauma – Johnson & Johnson institute	2018	0.8
Symposia and congresses		
- Poster presentation Conference Minnesota Orthopaedic Society	2013	0.25
- Visiting scientific congresses: NOV (4x), NVA (1x), VOCA (1x)	2016-20	2.00
- Poster presentation: NOV 2016, NVA 2016	2016	0.5
- Presentation on symposium 'Patellofemorale klachten' on treatment after patellofemoral surgery, CWZ	2018	0.25
- Organizing resident symposia on Foot and ankle surgery in Sint Maartenskliniek	2020	2
Other		
- Visiting weekly Seminars and lectures St. Maartenskliniek and RadboudUMC (approx. 80)	2019-20	8
- Co-organizing Sports Event for Orthopedic surgeons and Residents	2017	1
- 3 month visiting internship dr. E.A. Arendt, orthopedic surgeon, member of International Patellofemoral Study Group, Minneapolis, Minnesota, USA	2012	12
Lecturing / education / Supervision interships		
Student internship coaching (Approx 1/2-hour supervision per week)	2017-20	5
Journal clubs and clinical presentations in St. Maartenskliniek and RadboudUMC (6x)	2016-20	6
TOTAL		60.5

About the author

Jordy Dominicus Petrus van Sambeeck was born on April 24th, 1991 in Helmond. After living in Griendtsveen the first two years of his life, his family moved to Eersel, situated in the region 'De Kempen' near Eindhoven. Together with his younger brother Davey, Jordy was raised here. In 2009, Jordy finished the Atheneum at the Rythovius College in Eersel and graduated with honor. He went to medical school at the Radboud University in Nijmegen and lives in Nijmegen since then.

During his first year of medical school, Jordy sustained an anterior cruciate ligament rupture during a soccer game and a surgical procedure was needed. That was when he started to gain interest in the world of orthopaedic surgery. Next to medical school, Jordy worked as a surgical assistant at the department of orthopedics at the Canisius Wilhelmina Hospital (CWZ), Nijmegen. After he completed his bachelor's degree with honor, he went abroad for 3 months and completed an internship at the department of orthopedics at the University of Minnesota (Minneapolis, MN, USA) under the supervision of dr. Elizabeth Arendt. During this internship, Jordy gained specific interest in the patellofemoral joint.

During the last year of medical school, Jordy performed his senior clerkship at the department of orthopaedic surgery of different hospitals in and around Nijmegen (Radboudumc, Sint Maartenskliniek and Rijnstate Hospital). During this year, Jordy started the first research projects for this thesis.

His clinical career started as a non-residential doctor at the Sint Maartenskliniek, under supervision of dr. A.B. Wymenga and dr. V.J.J.F. Busch. In June 2017, he started as a resident at the department of orthopaedic surgery in the CWZ, where he worked under the supervision of drs. F.Polat. In January 2019, he continued his training in the Sint Maartenskliniek. In July 2020, he continued his residency in the Radboudumc. Meanwhile, he performed research for his PhD thesis, encouraged by dr. S. Koeter and dr. ing. S.A.W. van de Groes. This led to the completion of this thesis with as main focus osteotomies for the treatment of patellofemoral instability.

Currently, Jordy is in his fifth year of residency at the department of orthopaedic surgery in Rijnstate Arnhem. He will finish his training in 2023. He lives in Nijmegen with his wife Senja, whom he married in August 2021.

Dankwoord

Ik ben ontzettend blij en trots dat ik mijn proefschrift heb kunnen afronden! Zonder de hulp en het vertrouwen van velen zou me dat niet gelukt zijn en ik ben dan ook dankbaar voor alle hulp die ik heb mogen ontvangen. Het was een leuke, maar soms ook pittige weg. Als ik mijn promotietraject met een van de monumenten in het wielrennen zou mogen vergelijken, is het Luik-Bastenaken-Luik, met dit proefschrift als trofee aan de finish.

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Ik heb kunnen fietsen over de wegen die jij geplaveid hebt, dank daarvoor!

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Het was mij een eer om samen met jullie dit parcours te mogen afleggen. Dank dat we elkaar de heuvels over gesleept hebben en dat we elkaar hebben laten zien hoe het parcours loopt!

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Jullie bijdrage was onmisbaar! Dank dat jullie mijn koers mee op gang gehouden hebben!

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Op sommige delen van het parcours was ik lichtelijk verdwaald, dank dat jullie mij daar de weg gewezen hebben!

Dear dr. Arendt, Dear Liza,
I am very thankful for the time I spent with you in Minneapolis. You taught me the basics and much more of the patellofemoral joint. While I still needed 'training wheels', you put me on the bike by giving me the freedom to do research, to write case reports, to go to conferences and showed me how to perform patellofemoral surgery. Next to that, your hospitality was amazing! Thank you for all these opportunities and teaching me to ride on two wheels!

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Bedankt voor het vertrouwen dat jullie in mij uitspraken door mij aan te nemen voor de opleiding tot orthopedisch chirurg. Het door mogen gaan op dit kruispunt, was de beste motivatie om door te gaan met deze tocht!

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Beste collega AIOS orthopedie,
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Beste Philip, we leerden elkaar kennen tijdens mijn eerste baan, daarna zijn we kop over kop verder gereden over het parcours van de orthopedische wereld. Jij hebt mij onderweg ook veel geleerd over het leven naast de fiets. Dank voor je vriendschap, je collegialiteit en je verhelderende blik op het leven op én naast de fiets!

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momenten beleefd hebben. Ik ben ontzettend benieuwd naar wat we nog samen gaan meemaken! One skin, one love.

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Bedankt dat je mij door de laatste kilometer geloodst hebt en de eindsprint voor me hebt aangetrokken!

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Samen hebben wij de basis gelegd om ieder zijn eigen weg in te kunnen slaan. Ik ben ontzettend trots dat ik samen met jullie vanaf ons 14e levensjaar de wegen van de wereld heb kunnen ontdekken. Daardoor staat eenieder van ons als individu op een plek waar we toen over droomden. We hebben veel tochten samen volbracht en dat zullen we blijven doen! Dank voor jullie onvoorwaardelijke vriendschap!

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Zo lang ik mij kan herinneren was er altijd jullie oprechte interesse in mij en daarmee ook in mijn studie, loopbaan en onderzoek. De tochten die jullie zelf hebben volbracht, hebben mij geïnspireerd om zelf ook een tocht te gaan maken. Dank voor jullie interesse, inspiratie en aanmoedigingen!

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Attachments

Chapter 7, Table 1. Study characteristics.

Author Year	Nr. of patients included	Nr. of knees	Duration symptoms before surgery	Mean age surgery in years (range)	Sex (% female)	Follow up (mean in months)	Nr. knees lost to FU	Type trochleo-plasty	Tibial tubercle transfer	Medial soft tissue proce-dure	Miscell-aneous	Post-operative compli-cation related to trochlea-plasty (nr. of patients)	Major compli-cations (number; percentage)	Minor compli-cations (number; percentage)
Lateral facet elevating trochlear osteotomy														
Badhe et al. 2003	4	4	Long history	32 (24-38)	75	12	0	Albee	0	0	4 patellar osteotomy	10-20 degrees loss of flexion (4)	0; 0%	4; 100%
Koëter et al. 2007	16	19	N/A	25 (15-34)	N/A	51	0	Modified Albee	0	0	-	Postoperatieve haematoma that had to be evacuated (1) 1 grade progression of osteoarthritis (2) Subluxation after rotation trauma (2), 1 undergoing reposition of the tibial tubercle which was transposed in a former procedure Persisting pain treated with patellofemoral arthroplasty (1)	3; 16%	3; 16%
Bereiter trochleoplasty														
Banke et al. 2014	17	18	N/A	22,2	65	30,5	0	Bereiter	0	18 MPFL	-	Medial subluxation undergoing patella readjustment (1) Reduced ROM undergoing early arthroscopic arthrolysis (2)	3; 17%	0; 0%
Camathias et al. 2016	44	50	> 6 months	15,6 (13-20)	60	33	0	Modified Bereiter	0	0	-	Spontaneous redislocation (1) Arthrofibrosis requiring arthroscopic arthrolysis (4)	5; 10%	0; 0%

Fucentese et al, 2011	38	44	N/A	18 (median) (14-40)	75	48 (median)	4	Deepening Bereiter	0	44 VMO	-	Transient postoperative femoral nerve palsy after peripheral anesthesia (1) Wound healing problem (1) Complex regional pain syndrome (1) Ongoing pain undergoing arthroscopic debridement with removal of loose bodies (3) Ongoing sensation of instability during activities of daily living (6), 1 undergoing MPFL reconstruction and 1 anteromedialization of the tibial tuberde Recurrent atraumatic dislocation (1)	6; 14%	7; 16%
Metcalfe AJ, 2015	185	195	N/A	21	72	minimum 1 year	19	Deepening Bereiter	N/A	N/A	-	Ongoing dislocations (16)	16; 8%	0; 0%
Nelitz et al. 2013	23	26	N/A	19,2 (15-23)	38	30	N/A	Deepening Bereiter	0	26	-	No complications reported	0; 0%	0; 0%
Schöttle et al. 2005	16	19	N/A	22 (17-40)	81	36	0	Deepening Bereiter	0	19 VMO	-	Increased degenerative changes of the trochlea (1)	0; 0%	1; 5%
Utting et al. 2008	54	59	mean 7 years	21,5 (14.3-33.9)	72	24	13	Deepening Bereiter	4	14 MPFL & VMO 5 VMO 4 MPFL	-	Superficial wound infection (2) Manipulation under anesthesia (1) Traumatic dislocation (1) Anaphylactic reaction after administration of prophylactic antibiotic on induction of anesthesia (1) Recurrence of symptoms (10)	2; 3%	13; 22%

Von Knoch et al. 2006	38	45	N/A	22,2(15-31)	58	99,6	3	Deepening Bereiter	0	45, MPFL as required	-	Patella baja (1) Subluxations undergoing additional Elmslie-Trillat procedure (1) Progression of PF OA to Iwano grade 1 (14), 2 (7), 3 (2) or 4 (1)	2; 4%	24; 96%
Neuman et al. 2014	42	46	N/A	27,6 (median) (16-53)	72	56,7 (median)	20	Deepening Modified Bereiter	0	46 VMO & MPFL	-	Radiological progression of PF OA (3)	0; 0%	3; 7%
Bereiter and Gautier 1994	10	12	N/A	20 (15-30)	70	24	6	Bereiter	N/A	N/A	-	Postoperative bleeding (1) Algodystrophy (1)	0; 0%	2; 17%
Arthroscopic deepening trochleoplasty														
Blond and Haugegaard 2014	31	37	9-348 months	19 (median) (12-39)	68	12-57 (range)	0	Arthroscopic deepening	0	37 MPFL	-	Pronounced anterior knee pain at flexion undergoing lateral release (3) Symptomatic subluxations corrected by medialization of the tibial tubercle (2)	5; 14%	0; 0%
Dejour trochleoplasty														
Dejour and Ntagiopoulos 2013	22	24	N/A	23 (14-33)	75	66,5	0	Deepening (Dejour)	12	11 MPFL 10 VMO	6 lateral release 1 patellar osteotomy 4 PT lengthening & proximal TT transfer	No complications reported	0; 0%	0; 0%
Faruqui et al. 2012	6	6	N/A	21,5(15-38)	83	68,3	6	Deepening	3	3 MPFL 2 imbrication	-	Mentioning of complications absent	0; 0%	0; 0%

McNamara et al. 2015	90	107	N/A	23 (12-49)	60	72	N/A	Deepening (modified Dejour)	11	14 MPFL 16 patello-plasty 28 lateral release	Venous thrombotic event (2: 1 DVT, 1 PE) Superficial wound infection (4) Complaints of significant crepitus (4), 2 underwent patelloplasty Continuing instability symptoms undergoing MPFL-reconstruction (10) Arthroscopic arthrolysis (7), open arthrolysis (1) Removal of loose absorbable screw heads (2) Arthroscopic debridemnt of a notch "osteophyte" (1)	24; 23%	7; 6,5%
Ntagiopoulos et al. 2013	27	31	N/A	21 (14-47)	48	94	0	Deepening (Dejour)	21-31	5 MPFL 26 VMO	21 lateral release	Hardware breakage that had to be removed by arthroscopic surgery (2) Deep venous thrombosis (1)	2; 7%	1; 3,2%
Rouanet et al. 2015	34	34	N/A	27,8 (16-49)	71	183,6	11	Sulcus deepening	17	34 Insall procedure		Postoperative stiffness at <90° flexion requiring manipulation under anesthesia (6) or arthroscopic release (2) Pain and Iwano stage 4 PF OA undergoing total knee arthroplasty (3) or patellofemoral arthroplasty (3) Pain and frequently giving out of the knee requiring anterior tibial tubercle transfer (1) Occasional instability (10) Progression of PF OA to Iwano stage ≥ 2 (22)	15; 44%	32; 94%

Modified deepening trochleoplasty														
Zaki and Rae 2010	25	27	N/A	25 (19-36)	72	54	N/A	Deepening	5	3	14 medial reefing + Roux procedure (8 + VMO)	Superficial wound infection (3)	0; 0%	3; 11%
Recession wedge trochleoplasty														
Thaunat et al. 2011	17	19	mean 11 years	23 (18-45)	56	34	1	Recession wedge	18	8 MPFL	19 lateral release	Knee stiffness requiring arthroscopic arthrolysis (1) Painful persistent ridge requiring arthroscopic supratrochlear exostosectomy (1) Traumatic dislocation (1) Recurrence of instability (1) Progression of PF OA to Iwano stage 2 (3)	3; 16%	4; 21%