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Patellofemoral Instability : Part II
Bony Procedure for Patellar Surgical Stabilization

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Bony Procedures for surgical patellar stabilization

Abstract

Surgery for patellofemoral instability is usually considered in patients with recurrent patellar dislocation and after a first-time patellar dislocation in the presence of either an associated osteochondral fracture or high risk of recurrence due to the presence of several risk factors. Risk factors include demographics such as age, contralateral dislocation, as well as anatomic risk factors (ARF) such as abnormal coronal and rotational alignment, trochlear dysplasia, lateral quadriceps vector, and patella alta. Surgery with soft tissue procedures includes restoring the medial patellar restraints and balancing the lateral side of the joint and can be successful in most patients. However, patients that have excessive and/or several ARF have a high risk of failure with isolated soft tissue stabilization procedures; associated surgical correction of select ARFs is recommended. This article will discuss an approach to evaluate the risk-benefit of adding bony procedures which may decrease the changes of recurrence of patellar instability but can increase surgery-related complications. Approaching patellofemoral instability in a patient-specific approach and combining corrective osteotomies and trochleoplasties with a shared decision with the patient/family, guiding surgeons to deliver optimal care for the patellar instability patient.

Introduction

As the understanding of the pathoanatomic variables that contribute to lateral patellar dislocations (LPD) mature, so are the techniques to address these anatomic contributors of instability. The cornerstone of surgical patellar stabilization for treatment of LPD is Medial Patellofemoral Ligament Reconstruction (MPFL-R). Current evidence will be reviewed describing the indications and outcomes of bony procedures that are part of the current algorithm to address surgical patellar stabilization including coronal and axial plane osteotomy, tibial tubercle osteotomy (TTO), and trochleoplasty are part of current surgical treatment algorithms to best manage patients recurrent LPD.

Varus Producing Distal Femoral osteotomy (DFO)

Coronal alignment of the femur has been shown to considerably alter patellar tracking[1]. Increasing degrees of distal femoral valgus result in an increasing lateral force vector across the patella. A few studies with small sample sizes have investigated the utility of performing a DFO for excessive valgus in patients with patellar instability, as well as anterior knee pain without instability. The short-term outcomes of these studies are encouraging[2, 3]. However, many of these studies have a mixed population of anterior knee pain +/- patellar instability. No clear threshold has been defined as an excessively valgus mechanical axis contributing to patellar instability. However, Frings et al utilized ≥5º of mechanical axis valgus as their threshold to perform a varus DFO, especially in the setting of co-existing lateral compartment femorotibial degeneration[4]. A distal femoral lateral opening wedge osteotomy (Figure 1) or a medial closing wedge osteotomy (Figure 2) can be utilized. Choice is surgeon dependent based on other factors including concomitant surgery, age, bone density, body mass index.

Caution must be exercised to not generalize the femur as the sole culprit in a valgus mechanical axis. Eberbach et al demonstrated that combined femoral and tibial contributions to the overall mechanical valgus axis were more common than isolated femoral contributions.

Furthermore, the authors concluded in knees with ≥5º of mechanical axis valgus, 55.2% of ideal osteotomies would be performed in the tibia and 25.2% would be a double level (femur and tibia) osteotomy[5]. Complications derived from literature in which DFOs are performed for lateral femorotibial arthritis demonstrate a low complication rate, consisting of mostly hardware related issues, especially if a lateral plate is used[6, 7].

In the setting of PF instability, as with other pathologic anatomic variances, a holistic approach should be taken and the pros and cons of correcting each contributing factor must be weighed. Most authors agree to add a varus producing DFO when there are at risk issues with the lateral tibio-femoral compartment (chondrosis, lateral meniscus tear, osteochondral dissecans). More research is needed to better define the contribution and significance of valgus plane coronal alignment to patellar instability and at what threshold surgical correction is desired for optimal outcomes.

Though outside the scope of this review, in a child with valgus knee(s) with open physes, guided growth should be considered[8-10].

Derotation Femoral osteotomy

Maltorsion of the femur can impair joint moment generation, which can result in adverse effects on joint health and gait compensation. Under-detection and under-treatment of transverse plane deformity of the tibia and femur result from lack of clinical awareness, as well as challenges of the accuracy and reliability of both physical examination and imaging measurements[11]. The physician may become suspicious during the physical exam (e.g. in-toeing and out-toeing gait; prone increased hip internal rotation with decreased hip external rotation), and plain films, femoral condyle/lateral tibial eminence superimposition, > 2mm or prominent lateral femoral condyle and a small and narrow medial femoral condyle)[12]. (Figure 3.). Torsional deformities are then verified by slice imaging (MRI or CT). (Figure 4)

The use of 3D data generated by stereo-radiographic system (EOS™) (low dose biplanar radiography) holds promise for assessing biplanar limb alignment, which greatly reduced scan time and radiation exposure to the patient[11, 13].

Maltorsion of the femur and/or tibia can contribute to PF instability as well as pain. Several recent studies outline the effects of increased torsion, in particular excessive femoral anteversion, on patella instability[14-18]. Awareness of maltorsion is crucial, though surgical threshold for correction continues to be debated. In a cadaveric study, isolated Medial Patellofemoral Ligament (MPFL) reconstruction failure has been reported for increased femoral anteversion (internal femoral torsion) of >20º over normal[16]. However, a recent clinical cohort study on patients with lower limb torsion revealed that trochlear dysplasia but not torsion predicted lateral patellar instability[14].

When a “J sign” is present on clinical exam, femoral anteversion should be scrutinized and evaluated by slice imaging if suspected on clinical exam.   A recent retrospective study has shown that patients with an increased femoral anteversion angle (> 30°) had inferior postoperative clinical outcomes, including greater patellar laxity (as measured by patellar lateral translation), a higher rate of residual J-sign and lower patient-reported outcomes after medial patellofemoral ligament reconstruction and combined tibial tubercle osteotomy for the treatment of recurrent patellar instability[19].   Yang et al. found good clinical outcomes in patients with LPD treated with distal femora derotational osteotomy and medial retinaculum plasty for femoral anteversion > 25º[20].   A recent systematic review found that femoral internal torsion greater than 25º and/or external tibial torsion greater than 30º as measured by CT are threshold values for axial alignment correction in patellofemoral Instability[8].

Ideally the femoral osteotomy should be performed near the region of the deformity as an inter-trochanteric, diaphyseal, or supracondylar osteotomy, all of which have been shown to have favorable outcomes in restoring patellar stability[15], and redistributing PF contact pressures[21]. (Figure 5).   If a supracondylar derotation osteotomy is performed with an MPFL reconstruction, care must be taken in planning for MPFL femoral fixation (Figure 6). When preparing for a derotational femoral osteotomy, the surgeon must consider the resultant coronal angulation changes that will ensue after osteotomy, notably (potential) increased knee valgus. Increased valgus can lead to a greater lateral quadriceps vector, potentially worsening the patellar instability. Several recent studies have demonstrated excellent outcomes in derotating excessively anteverted with significant decreases in VAS scores, increases in patient reported outcomes (PRO), and no recurrent dislocations[20, 22-24].

If the surgeon is confronted with both valgus and torsional femoral deformity, an oblique derotating DFO may be performed according to Imhoff et al.'s published calculation[25]. Alternatively, an IM rod could treat a bi-plane correction (Figure 7)

<u>Derotation Tibial Osteotomy</u>

Maltorsion of the lower leg may contribute to patellofemoral instability, knee pain secondary to altered biomechanics, possible aesthetic issues and stumbling due to pathologic in- or out toeing [26]

External tibial torsion has been associated with abnormal patellar contact pressures, dynamic knee moments, as well as decreased power generation of the foot/ankle complex resulting in lever arm dysfunction[27].

External tibial torsion may create an apparent lateral position of the patellar tendon insertion, and increased rotation between femur and tibia. It has been tempting for PF surgeons to try and solve this problem by medialization of the tibial tubercle, but this does not correct the out of plane foot position. Medial tibial tubercle osteotomy may reduce an elevated Q angle vector but does not improve faulty body movement patterns[11]. One should be certain that the Q vector is due to laterization of the tibial tubercle if one plans on surgically medializing the tibial tuberosity.

Similar to femoral maltorsion, the physical exam will show increased thigh-foot angle (effectively measured), which can be associated with increased quadriceps angle (Q-angle) and pathologic foot progression angle[11]. The suspicion from the physical exam is then verified by slice imaging. As with the femur, it is important for the clinician to be consistent with one's measuring technique [28].

Gait analysis (GA) is an alternative way to measure limb torsion; it provides dynamic, functional information that is lacking with static imaging methods. GA shows good correlation with CT measurements for the tibia. However, given the lower accuracy for hip rotation on gait analysis, combined CT and GA data may produce the most useful rotational assessment for the femur and/or limb at this time [11]. EOS holds great promise for skeletal radiography, given its advantages of transverse plane analysis with the patient standing and low radiation exposure[29]

Recent publications reported mean external torsion values of approximately 30° in healthy individuals[30, 31]. Forward dynamic simulations show that tibial extorsion 30° above normal reduces the capacity of the soleus, posterior gluteus medius, and gluteus maximus to extend the hip and knee[32]. Although the role of excessive external tibial torsion and altered knee/limb biomechanics is well established, it role as a risk factor for patellar instability is less clear, especially when not accompanied by excessive femoral anteversion. More research is needed to better define the significance of isolated external tibial torsion's contribution to patellar instability, and at what threshold surgical correction is desired for optimal outcomes.

If indication for derotation at the lower leg is determined, a variety of published osteotomy levels and techniques may be considered: a) at the level of the tubercle with an additional tubercle osteotomy (Figure 8), b) at the level of the tubercle with an anterior ascending cut (bi-planar) (Figure 9), c) proximal to the tubercle monoplanar d) just distal to the tubercle, e) mid-shaft, and f) supramalleolar [33-35]. (Figure 10). Besides personal preferences in osteotomy level and fixation technique, one must consider that derotation above the tubercle alters lateralization of the tibial tuberosity and thus the Tibial tubercle-trochlear Groove (TT-TG) distance and other such measurements, while derotation below the tubercle does not. Additionally, a supra-malleolar can be done with open phyes and therefore is the preferred technique in children.

Another consideration is the question of a concomitant fibular osteotomy. Based on the literature, the question of “if and when” a fibular osteotomy is needed is still unclear. Satisfactory results have been identified for each with relatively low risk. While it is not universally adopted, trends in the literature point to performing an isolated osteotomy of the tibia unless a full rotational correction cannot be achieved without a fibular osteotomy. This is somewhat dependent on patient age (degree of plasticity), and degree of tibial osteotomy correction.

Derotation tibial osteotomies for excessive external tibial torsion can be a surgical solution for both anterior knee pain (often with isolated excessive external tibial torsion), patellar instability (with either isolated excessive femoral anteversion, or combined with tibial maltorsion). A recent systematic review of reasons for surgical derotation tibial osteotomies (DTO) identified 22 studies for inclusion, with 658 tibias in 477 patients. Of all included patients, 48% underwent isolated DTO with the most common surgical indications for DTO being anterior knee pain (86%), patellar instability (59%), gait dysfunction (45%), and cosmetic deformity (18%), in isolation or combination. All patients who underwent surgery had either anterior knee pain or patellar instability, even if other indications were present [36].

No “gold standard” in thresholds and/or indications for DTO surgery has been advanced, in part due to multiple variables including skeletal maturity, magnitude of correction, or need for concomitant procedures. Oftentimes femoral and tibial maltorsion are combined with other anatomic issues in complex PF instability patients (Figure 11)

<u>Tibial tubercle osteotomy</u>

Tibial tubercle osteotomy (TTO) offers a surgeon the ability to redirect patellar tracking and/or PF stresses by changing the quadricep vector, correcting for patella alta, and/or redistributing the load within the PF articulation. The customizability of the TTO is afforded by the direction the tibial tuberosity is translated, determined by the surgical objective. The most common goals include the use of medializing TTO to re-direct an increased lateral tibial tubercle causing an increased quadriceps vector, distalizing TTO for reduction of patella height, and anteromedializing TTO (AMZ-TTO) to off load the distal lateral patella. Less commonly utilized TTOs include an anterior transfer TTO to off load a focal cartilage lesion with normal PF alignment, anterolateralizing TTO in revision settings after an excessively medialized TTO, or a proximal transfer TTO for patella baja.

When making the decision of whether a patient needs a TTO, and which TTO will provide optimal clinical outcomes, one should use a combination of focused physical examination and knee imaging. Initially the physical exam focused on the "q angle' or quadriceps vector. Brattstrom[37] defined the Q-angle as a valgus angle formed by the ''quadriceps resultant + patella + ligamentum patellae''. H. Dejour and colleagues attempted to 'objectify' the q-angle and popularized the tibial tubercle -trochlear groove distance, which is determined from axial slice imaging[38]. In their seminal article, they established this as anatomic risk factor for 'objective' recurrent lateral patellar dislocation (LPD).

Historically, the most common surgical approaches for the treatment of LPD have been to reduce a 'valgus' Q-angle. Biomechanical studies have suggested that the stabilization of the patella is not accomplished by medial tibial tubercle transfers[39]. Moving the tubercle may have negative long-term consequences. Medial transfer of the tibial tuberosity can result in a increase in external tibial rotation[40, 41], and increase in medial tibiofemoral compartment pressure[42]. One helpful technical intra-operative pearl to prevent over-medialization of the tibial tubercle is to look at the tubercle sulcus angle (TSA), which some call the 'sitting' Q angle. (Figure 12). The TSA is a physical exam measurement that gives insight into the position of the quadriceps vector in flexion, as the distal arm of the quadriceps vector may change as the tibia internally rotates during flexion[43, 44]. A normal TSA is zero at 90° of knee flexion. TSA can be used pre-op to evaluate the need for TTO medialization, or intra-op to assess final placement of the medialized tubercle[45].

The role of increased quadriceps vector as a risk factor for lateral patella dislocation must be challenged in-light-of current-day knowledge. It is a linear measurement not a ratio as such size is not taken into account and can be a source of variability. ‘Normative’ values differ between CT and MRI. TT-TTG distance changes with chronologic age in the pediatric population[46]. The TT-TG measurement is a result of 3 separate measurement: lateralization of the tibial tubercle, rotation between the tibia and femur, and medialization of the trochlear groove (as in high grade trochlear dysplasia)[47]. (Figure 13a-c). The TT-TG distance value should be scrutinized and not used as an isolated value.

More focused patellar tracking examination should specifically assess for the presence of a J sign, seen with dynamic knee flexion and extension[48]. One proposed classification for the J-sign is[49]: 1) normal patellar tracking: patella is centralized in the groove at 90 degrees of flexion, and as the patient actively extends the knee, the patella remains central until full extension (physiologic mild lateral shift and external tilt can occur in some patients); 2) abnormal glide: the patella is centralized in the groove at 90 degrees of flexion, and as the patient actively extends the knee, there is a smooth glide towards excessive lateral shift of the patella (subluxation or dislocation in extension). Conversely, during active knee flexion, the excessively lateralized patella smoothly glides to the groove to a reduced position. 3) Abnormal clunk: patella is centralized (reduced) in the groove at 90 degrees of flexion. As the patient actively extends the knee, there is an abrupt change in patellar tracking with sharp lateral shift of the patella (subluxation or dislocation in extension). Conversely, during active knee flexion, the lateralized patella sharply enters the groove to a reduced position. This distinction between a smooth lateral translation and an abrupt translation may signify the presence of a bony prominence anteriorly from high grade trochlear dysplasia, causing a sharp lateral shift of the patella, and/ or excessive femoral anteversion. A “type 3” or J sign ‘cluck’, typically signifies the need for a bony correction for optimal patellar stabilization, and not a soft tissue procedure alone.

To help guide decision making whether and which type of TTO is appropriate, knee radiographs and knee slice imaging (typically MRI) should be carefully evaluated, in particular, analysis of patellar height, lateral tubercle offset, geographic location of patellofemoral chondrosis.

Once this data has been collected, it should be synthesized with other patient specific factors such as activity level and age, to suggest the best plan of action. The rationale to include TTO is based on presence of anatomic abnormalities (increased quadriceps vector and patella alta) as well as location of cartilage lesions when present. Rotational malalignment (increased femoral anteversion, increased knee rotation and increased tibial external torsion) may present itself as an abnormal lateral quadriceps vector in extension and normal in flexion. In those cases, the increased lateral quadriceps vector may be due to the rotational malalignment and not due to a laterally positioned tibial tuberosity, particularly in a varus knee[15, 50]. Careful consideration of coronal and rotational alignment of the knee must be taken, as medialization of the tibial tubercle in a knee with increased knee coronal alignment and/or axial rotational deformities may result an increase in TT-TG measurement not related to lateralization of the tibial tubercle, and can result in an over medialized tibial tuberosity.

Historically, medialization TTO (Elmslie-Trillat Technique) was indicated for patients with recurrent LPD and increased lateral quadriceps vector (TT-TG/TT-PCL distance), without any significant PF cartilage lesions[38]. In biomechanical cadaveric studies, medialization of the tibial tubercle reduced lateral PF contact forces with no excessive increase in medial patellar pressures or motion. [50]. For what clinical PF condition and at what threshold of TT-TG distance medial TTO is necessary for optimal clinical outcomes is controversial, in particular

TTO medialization is used to stabilize the patella. This change in its use is largely dictated by the use of MPFL-R. Current literature offers mixed results. Franziozi, et al., demonstrated improved patient reported outcomes when TTO was performed with MPFL reconstruction in patients with borderline TT-TG measures of 17-20mm[51]. Similarly, in patients with TT-TG >20mm, Mulliez et al[52] and Neri et al[53] found improved PROs with adjunctive medial TTO to MPFL reconstruction. Others have found not change in re-dislocation or patient reported outcomes with isolated MPFL-Reconstruction and no medial TTO in patients with TT-TG >20 mm by CT measurement[54].

The use of a medial or anteromedial TTO in most current algorithms is indicated for chondrosis of the inferior/lateral patellofemoral joint [55] due to the load shifting principles of this operation. There is no consensus on the threshold of lateral quadriceps vector measures to suggest AMZ with a focal cartilage lesion. Though studies have shown no association of TT-TG distance as a risk factor for PF cartilage lesions[56, 57], the offloading of the lesion is supported by clinical data[55, 58]. Using the intra-operative physical exam sign of a tubercle sulcus of zero, is a convenient way to avoid over-medialization of tibial tubercle[59]. It is important to highlight that medial patellar facet lesions can be a consequence of lateral patellar dislocations and would benefit from patellar stabilization, while medial sided patellar facet lesions may also be a consequence of medial patellar overload/idiopathic induced lesions (typically associated to varus knee), or iatrogenic due to overcorrection of medial TTO and or a too tight MPFL reconstruction.

Blumensaat was one of the first to recognize patella position and its relationship to LPD[60]: the relationship of patella alta as a primary anatomic risk factor has been noted by numerous subsequent authors[38, 61, 62].

Methods of measuring patella height is elsewhere reported[63], though most measuring schemes relate the patella to the tibia. Most measurements were initially analyzed on sagittal radiographs; the agreement between measurements on MR sagittal slice image and lateral radiographs has been recently analyzed and found that MR imaging overestimates patellar height compared to radiographs[64, 65].

The importance of measuring patella's sagittal position in relation to the trochlear groove is a critical factor when combined with trochlear dysplasia, which often results in a flat but also shortened sulcus. This ''functional engagement'' of the patella with the trochlear is best defined by the relationship of the patella with the femoral groove. A femoral based measuring method associating the patella to the groove on lateral radiographs was introduced in 1969 by Bernageau, a French radiologist[66]. The method was not widely accepted. Patella position in the sagittal plane was further analyzed by MR imaging, with thresholds for patella to femoral cartilage contact more precisely defined[67, 68]. (Figure 14)

There is little evidence to support the accuracy and validity of any one method, and none has proved to be suitable for universal application. Establishing normal values and pathologic thresholds would require a very large population. Measurement of patella height, along with patellotrochlear engagement, remains an important clinical entity. Knowledge of when to surgically correct this risk factor remains a clinical challenge. A blended approach of patella height with functional engagement parameters should be used to help guide surgical algorithms[59].

Distalizing TO is the most common surgical procedure to correct excessive patella alta. (Figure 15a-c) The goal of this osteotomy is to improve the engagement of the patella with the trochlea earlier in the flexion arc, thus increasing bony stabilization earlier in early flexion. One clinical study reported on the outcomes of 211 patients with a 3 year follow up and found that a CDI > 1.3 has an odds-ratio (OR) of 5.5, as a risk factor for isolated MPFL failure[69]. However, when TTO is performed in conjunction with MPFL reconstruction (MPFL-R) for mild patella alta (CDI 1.2-1.4) the PROs have shown no difference. Medial or anteromedial transfer of the tibial tubercle can be combined with distalization when indicated. With the addition of MPFL-R to our surgical armentarium, the surgical threshold for patella height is changing, allowing greater patellar height measurement to be treated without a distal TTO. Clinical outcomes using a blended approach to patellar height measurement, using a C/D ratio > 1.4 or a patella-trochlear index (PTI) of <.20 has shown good objective outcomes[59, 70].

Special consideration for TTO may also be taken in the presence of a trochlear bump with or without a suggestive clunk J-sign. A TTO in this setting may be able to change the patellar tracking by 'by-passing' the trochlear bump thus avoiding articulation with the bump, especially in the presence of patella alta; possibly obviating the need for trochleoplasty[59].

Additional variables that may lower the threshold for TTO include the following: patients with knee hyperextension/ligamentous laxity (Beighton score), athletes engaged in high-risk sports (cutting/pivoting/contact), and PF pain from lateral/distal overload pathology (OA, cartilage lesions).

TTO is typically avoided in the skeletally immature population due to risk of growth arrest of the tibial apophysis which can lead to pathologic anterior tibial slope[71]. In the case of closing tibial physes, there is less risk of pathologic anterior tibial slope when reaching bony maturity, especially if there is normal to moderate posterior tibial slope.

The major concern when considering TTO is the associated morbidity and more complex postoperative rehabilitation[65]. Additionally, there is increased operative time associated with MPFL-R with TTO (122 ± 45 minutes) as compared to isolated MPFL-R (97 ± 55 minutes), or isolated TTO (89 ± 51 minutes). However, no difference was found with respect to hospital stay, 30-day readmissions, or adverse events among these three cohorts[72].

<u>Soft tissue realignment procedures substitute for TTO</u>

If a distal realignment is indicated in a skeletally immature individual with appreciable increase in expected growth, apophyseal sparing alternatives may be used to alter the lateral quadriceps vector. These include distal patella realignment procedures such as the Roux-Goldthwait procedure [73], which redirects the patella tendon insertion by medalizing the lateral half of the patellar tendon. These physeal sparing techniques, taken collectively, are favorable, with improved Lysholm scores, subjective outcomes, and redislocation rates[58, 73-75],but are less commonly done currently due to the utility of MPFL -R for recurrent lateral patellar dislocations, as well as the clinical debate over the necessity to medialize the tibial tubercle. Malecki and colleagues demonstrated equivalent outcomes (Lysholm/Kujala scores and redislocation rates) between Roux-Goldthwait procedures and isolated MPFL-R, however the MPFL-R had a lower incidence of pain[75]. Also, Silanpäa et al. conducted a comparative study between surgical patellar stabilization in adults utilizing MPFL -R using adductor magnus autograft, and distal realignment using Roux-Goldthwait. The authors reported superior findings of the MPFL group in terms of recurrence rate and knee scores[76]. Thus, MPFL has been suggested to be the superior choice amongst the two. One popular strategy is to due a MPFL-R to help stabilize the patella, with plans to do a more definitive bony procedure one growth plates have closed. This strategy does have higher risk of failure in children with increased knee rotation, especially in the setting of severe trochlear dysplasia and increased lateral patellar tilt[77].

When the surgeon is confronted with patella alta in an immature patient, patellar imbrication for patella alta, popularized by Jack Andrish and the Cleveland clinic, is one solution[71, 74]. This technique uses a split of the mid patellar tendon in the frontal plane (anterior and posterior sheet). The tendon is then shortened with suture-lifts similar to jalousies of a window dressing.(Figure 16 a-e) However, according to the authors' own experiences, the shortened tendon may stretch out to a certain extend; therefore, initial overcorrection may be considered.

As an alternative for the Cleveland clinic technique, a patella tendon advancement may be used when treating patellofemoral instability in immature patients with coexisting patella alta[78]. This technique has been used in patients with obligate patellar dislocation in flexion and in patients with cerebral palsy.

Currently, distal realignment procedures are utilized less frequency due to the clinical utility of MPFL-R in children and adults, and when used, are typically performed as adjuncts to MPFL reconstructions[59, 74].

Deepening Trochleoplasty (Trochlea Osteotomy)

Trochlear dysplasia is exceedingly recognized as a key risk factor for primary and recurrent patellar instability when considering the various anatomic contributors to patellar instability[38, 61, 79], and as such has become a major focus when deciding how to surgically restore patellar stability with the best outcomes. There are several surgical procedures to reshape the trochlea. These procedures have demonstrated success in restoring patellar stability, however their associated steep learning curve, increased invasiveness, and potential for chondral damage have limited widespread use.

Proper indications for a trochleoplasty are critical and require an understanding of the key underlying anatomic contributors to the patellar instability. This begins with a thorough history, focused physical exam, and imaging of the knee. During physical examination, particular attention is paid to the presence of an abnormal patellar tracking, in particular a type 3 J-sign, or J-sign clunk. This abnormal J-sign suggests a trochlear spur that is acting as a ramp causing abrupt lateral translation to the patella during knee ROM. Additionally, using the Dejour classification[80] the trochlea may be classified into one of the four categories (A-D, with fair intra-observer reliability) or as low grade (A) vs. high grade dysplasia (B-D, with good intra-observer reliability)[81]. However, the most important finding for operative decision making is the presence or absence of a (supra)trochlear spur/bump or trochlear prominence that prevents trochlear engagement of the patella. Suggested by the abnormal clunk J-sign, this (supra)trochlear bump is confirmed true lateral radiographs or axial/sagittal slice imaging (CT or MRI) studies. The bump/spur size can be measured from a line parallel to the anterior femoral cortex to the most anterior point of the trochlear spur (abnormal threshold, > 5-8 mm; so called anterior prominence or boss)[82, 83]. (Figure 17) A lower threshold may be appropriate in the presence of an abnormal clunk J-sign or excessive patella alta (CDI >1.4). Contra-indications to trochleoplasty include full thickness cartilage loss on the trochlea and skeletal immaturity. However, Nelitz et al recently published a cohort of 18 skeletally immature patients with <2 years of growth remaining in which a thin-flap trochleoplasty was performed. The authors reported no cases of growth disturbance or recurrent instability[84].

As for the various technique options, current evidence has not proposed a clearly superior technique. The most common techniques include the classic sulcus deepening Dejour ‘thick-shell’ technique[44], the ‘thin-flap’ technique[85] (Figure 18a-e) and the Peterson grooveplasty[86]. Schottle et al has demonstrated that the articular cartilage overlying the removed bone remains viable in the short term, with some changes of undetermined significance in the calcified cartilage layer[87]. Furthermore, the proximal trochlea or grooveplasty technique has been shown to offer a lower risk of articular cartilage damage at the cost of conferring less patellar stability by ‘shortening’ the groove[88]. Complication profiles have been shown to be comparable between the Bereiter/Dejour trochleoplasty and other stabilization procedures (MPFL-R, TTO, etc)[89]. Several systematic reviews have been conducted comparing trochleoplasty with non-trochleoplasty for trochlear dysplasia induced patellar instability[90, 91]. Song et al. evaluated 17 studies consisting of 329 knees in which a trochleoplasty (Dejour V-shaped deepening trochleoplasty, Bereiter U-shaped deepening trochleoplasty, and Goutallier recession trochleoplasty) had been performed, and 257 knees that underwent other procedures (MPFL -R)[90]. The principal finding in this review and that of Testa et al, was a dramatic post-operative improvement in all included studies regardless of the specific procedures performed, including both trochleoplasty and non-trochleoplasty procedures. However, the trochleoplasty cohort demonstrated superior results in post-operative patellar stability and lower degenerative PF arthritis; these knees exhibited lower range of motion (ROM) and revision rate when compared to the non-trochleoplasty group. Furthermore, Balcarek et al[92] in a ten study meta-analysis [6 trochleoplasty (n=186 knees) and 4 MPFL studies (n=221 knees] demonstrated that the addition of a trochleoplasty in conjunction with other procedures, including MPFL, lowered the rate of dislocation compared to isolated MPFL-R (2.1% vs. 7%, respectively). Taking a closer look, Zaffagnini et al, in a recent systematic review, showed that the addition of trochleoplasty to an MPFL-R confers a lower redislocation risk only in knees with severe trochlear dysplasia (Dejour C or D) but not in knees with mild dysplasia (Dejour A or B). In these mildly dysplastic knees, there was no difference in redislocation rates after MPFL-R +/- trochleoplasty, and there was a higher complication rate, most commonly restricted ROM/stiffness[93]. One study compared the Grooveplasty with Dejour trochleoplasty and concluded that both were viable option in the treatment of complex patellofemoral instability. The Grooveplasty patients showed less recurrent instability and similar PROs and reoperation rates compared with Dejour trochleoplasty. However, it's important to note that even though the degree of dysplasia, was not significantly different between the 2 groups regarding the Dejour classification type, it is possible that the patients with "larger" bumps were selected to undergo the Dejour trochleoplasty because a that would lead to an unacceptable large resection. In addition, patients in the grooveplasty group had more severe cartilage lesions and underwent through more cartilage restoration procedures as well as concomitant TTO; all those factors could have influenced the outcomes.

Trochleoplasty is a necessary procedure in the armamentarium of the surgeon treating complex PF deformities, and is often combined with other bony procedures with multifaceted dysplastic anatomy (Figure 19 a-c), it should be stressed that a shared decision making process should be taken, explaining the complications of trochleoplasty (cartilage damage, increase contact pressure from PF incongruence, arthrofibrosis and PF arthrosis[90] greater technical demands, and high variability of PROs (67-95% satisfaction)[14, 85, 94-97].

Conclusion

Lateral patellar instability is a complex problem with numerous players that may contribute to increased instability. With the use of a contemporary, evidence-based approach to pathomorphological variables that contribute to this instability, clinicians may more reliably treat PF instability. (Figure 20- the algorithm). Clinicians must approach PF instability in a case-by-case fashion and not a 'one-size fits all' manner, by properly identifying the constellation of contributors to the instability and appropriately addressing them.

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Legends for the Figures

Fig. 1a-c: Varus producing right knee distal femoral osteotomy (DFO).

- **a.** Intra-operative Coronal image of the distal knee undergoing a DFO
- **b.** Intra-operative photo of a right knee lateral open-wedge technique. The anterior aspect of the osteotomy is performed as ascending cut (bi-planar) technique.
- **c.** Post op coronal view of the knee with plate and screws in place.

Fig. 2a-b: Varus producing right knee distal femoral osteotomy (DFO).

- **a.** An intra-operative coronal image of right distal knee undergoing a medial closing-wedge DFO.
- **b.** Fixation is performed with an angle-stable plate.

Fig. 3: AP image of a right knee illustrating lateral femoral condyle (heavy black line)/lateral tibial eminence superimposition (heavy black dotted line) > 2mm (arrow), widened lateral femoral condyle with a narrow medial femoral condyle, suggesting limb version.

Fig. 4: CT axial images showing asymmetric bilateral femoral anteversion

Fig. 5a-c: AP images of femurs illustraing varying levels to correct femoral antetorsion:

- **a.** at the inter-trochanteric level fixed with a blade plate
- **b.** at the diaphyseal fixed with an IM rod
- **c.** at the distal femur fixed with a lateral plate and screws

The latter is the author’s (ML) preferred technique

Fig. 6a-c:

a. AP image of a left knee after a Derotational Distal Femoral Osteotomy with concomittant MPFL reconstruction.

b. Sagittal CT slice of same knee with interference screw noted in pink.

c. Axial CT slice of same knee. Note close vicinity of the femoral tunnel with interference screw fixation (pink) of the MPFL-reconstruction

Fig. 7: AP radiograph of a femur s/p osteotomies fixed with IM rod techniques. Note the 2 level correction axial alignment (proximal) and coronal alignment (distal lateral opening wedge)

Fig. 8: AP/ lateral radiographs of the tibia illustraing a derotation tibial ostetomy at the level of the tubercle with an additional tubercle osteotomy.

Fig. 9a-b: Intraoperative pictures of tibial derotational osteotomy at that level of the tibial tubercle.

a. planing of the biplanar osteotomy with ascending part at the tubercle.

b. bi-planar osteotomy after external rotation of the distal segment.

Fig. 10: AP/ lateral radiographs of the tibia illustraing a derotation tibial ostetomy at the level of the supramalleolar fixed with a plate and screws.

Fig. 11a-c: Postoperative images of a patient with patellar stabilization surgery including tibial derotational osteotomy, femoral derotational osteotomy, MPFL reconstruction and deepening trochleoplasty.

a. Lateral image of the proximal tibia with plate fixation

b. AP image showing screw and plate fixation after derotation at the distal femur and proximal tibial levels

c. Axial image showing a located patella.

Fig. 12: Illustration of the Tubercle- Sulcus Angle: with the knee in 90° flexion. Reference line from center of femur through center of patella; project line down the tibial shaft. Second reference line from center of patella to tibial tubercle. Perpendicular to femoral line, measure distance (mm) or angular measurement (degrees) to center point of tibial tubercle.

Fig. 13a-c: The TT-TG measurement is a result of 3 separate measurement:

- **a.** lateralization of the tibial tubercle = t/T (normal=0.65)
- **b.** rotation between the tibia and femur groove (through knee rotation) measured on slice imaging between lines drawn on the posterior aspects of the most distal femoral bicondylar line (dFCL) and the most proximal tibial condylar line (dTCL)
- **c.** medialization of the trochlear sulcus in high grade trochlear dysplasia

Fig. 14: Patellotrochlear Index (PTI): Measure on sagittal cut with greatest patellar length. The index is measurement of the overlap of the patellar and trochlear cartilage surfaces on MR slice imaging. PTI = E ÷ D Patalla alta is defined as ≤ 12.8%

Fig. 15a-c:

- **a.** Lateral radiograph of a knee after tibial tuberosity distalization. The previously resection bone can be transferred to the proximal defect and impacted, and acts as a buttress.
- **b.** An intra-operative photo of a chevron style ostetomy which can enhance the healing area.
- **c.** A lateral radiograph of the tibia after an isolated medial tibial tuberosity transfer leaving the distal cortical aspect of the cortical bone intact to work as a hinge.

Fig. 16a-e: Intra-operative photos of a patellar tendon shortening technique

- **a.** expsed patellar tendon [a=desired shortening, b= 0.5 a]
- **b.** frontal plane tendon split
- **c.** beginning of shortening and suturing of the posterior sheet
- **d.** completed shortening and suturing of the posterior sheet
- **e.** fixation of the anterior sheet

Fig. 17: 'True' Lateral radiograph of a distal femur. A line is drawn down the anterior femoral surface. The bone anterior to this line represents the boss or supra-trochlear spur.

Fig. 18 a-e: Surgical Steps of Deepening Trochleoplasty:

- **a.** exposure of the Trochlea,
- **b.** stepwise chisseling under the proximal trochlea,
- **c.** lifting the thin flap up to 90° in relation to the femoral longitudinal axis,
- **d.** removing bone stock underneath the flap with a chisel, refixation of the trochlea flap in the new bed with vicryl tape

Fig. 19a-c: Patient with recurrent lateral patella dislocation and severe trochlea dysplasia and maltorsion of the femur. Femoral maltorsion was determined as 35° (Yoshioka's method) and 43° (Waidelich's method).

- **a.** long leg AP view
- **b.** CT axial slice imaging illustrating the lateralized patellar position pre op
- **d.** Post operative CT axial slice imaging of same patient after deepening trochleoplasty and distal femoral derotation had been performed.

Fig. 20: A schematic diagram of treatment of Patellofemoral instability, including operative and non-operative pathways, and anatomic risk factors to consider in surgical planning.

Box 1
Key articles

Femoral osteotomy for patellofemoral instability

- Zhang Z, Cao Y, Song G, *et al*. Derotational Femoral Osteotomy for Treating Recurrent Patellar Dislocation in the Presence of Increased Femoral Anteversion: A Systematic Review. *Orthop J Sports Med*. 2021;9(11):23259671211057126.
- Frings J, Krause M, Akoto R, *et al*. Combined distal femoral osteotomy (DFO) in genu valgum leads to reliable patellar stabilization and an improvement in knee function. *Knee Surgery, Sport Traumatol Arthrosc*. 2018;26(12):3572–81.
- Imhoff FB, Beitzel K, Zakko P, *et al*. Derotational Osteotomy of the Distal Femur for the Treatment of Patellofemoral Instability Simultaneously Leads to the Correction of Frontal Alignment: A Laboratory Cadaveric Study. *Orthop J Sport Med*. 2018;6(6):1–10.

Tibial tubercle osteotomy

- Franciozi CE, Ambra LF, Albertoni LJB, *et al*. Anteromedial Tibial Tubercle Osteotomy Improves Results of Medial Patellofemoral Ligament Reconstruction for Recurrent Patellar Instability in Patients With Tibial Tuberosity-Trochlear Groove Distance of 17 to 20 mm. *Arthroscopy*. 2019;35(2):566–74.
- Sappey-Marinier E, Sonnery-Cottet B, O'Loughlin P, *et al*. Clinical Outcomes and Predictive Factors for Failure With Isolated MPFL Reconstruction for Recurrent Patellar Instability: A Series of 211 Reconstructions With a Minimum Follow-up of 3 Years. *Am J Sports Med*. 2019;47(6):1323–30.
- Pascual-Leone N, Chipman DE, Meza BC, *et al*. Concomitant anterior medializing osteotomy and MPFL reconstruction improves patellar tilt when compared to MPFL reconstruction alone. *Knee Surg Sports Traumatol Arthrosc*. 2023;31(8):3399-3404.
- Lundeen A, Macalena J, Agel J, *et al*. High incidence of complication following tibial tubercle surgery. *J ISAKOS*. 2023;8(2):81-85.

Trochleoplasty

- Askenberger M, Janarv P-M, Finnbogason T, *et al*. Morphology and Anatomic Patellar Instability Risk Factors in First-Time Traumatic Lateral Patellar Dislocations: A Prospective Magnetic Resonance Imaging Study in Skeletally Immature Children. *Am J Sports Med*. 2017;45(1):50–8.
- Song G-Y, Hong L, Zhang H, *et al*. Trochleoplasty versus nontrochleoplasty procedures in treating patellar instability caused by severe trochlear dysplasia. *Arthroscopy*. 2014;30(4):523–32.
- Zaffagnini S, Previtali D, Tamborini S, *et al*. Recurrent patellar dislocations: trochleoplasty improves the results of medial patellofemoral ligament surgery only in severe trochlear dysplasia. *Knee Surgery, Sport Traumatol Arthrosc*. 2019;27(11):3599–613.

Box 2

Validated outcomes measures and classifications

Patellofemoral joint specific

- Banff Patellofemoral Instability Instrument (PROMs) *
- Norwich Patellar Instability Score (PROMs) *
- Comprehensive Aachen Knee Score (COMPACK) (PROMs)
- Kujala Scoring System (PROMs) *
- Patellofemoral Pain Syndrome Severity Scale (PSS) (PROMs)
- Dejour's trochlear morphology classification *

Knee and general scales

- Patient-Reported Outcome Measurement Information System (PROMIS) (PROMs)
- International Knee Documentation Committee (IKDC) (PROMs) *
- KOOS (PROMs) *
- Short Form 12 or Short Form 36 (PROMs)
- Tegner Activity-Level Scale (activity level scale) *
- VAS: Visual Analog Score (pain scale)*
- Single Assessment Numerical Evaluation (SANE) (subjective pain-function scale)*
- International Cartilage Repair Society (ICRS) classification (cartilage lesions)*

*Authors preferred scores

PROMs: patient reported outcomes measures

Box 3
Key issues of patient selection

General considerations

- Patellofemoral instability is a multifactorial condition, demanding a thorough evaluation of anatomic and demographic risk factors for treatment decisions.
- When deciding on operative management, risks and benefits must individually weighed, with the history, physical examination and clinical signs, being the most important factors when considering which surgical procedure.
- It is not easy to predict the contribution of every correction to patellar tracking and stability, especially when combining these osteotomies.

Femoral osteotomy for patellofemoral instability

- Excessive valgus and rotational malignment should always be evaluated in PF instability.
- Consider significant contribution to the instability if mechanical valgus $\geq 5^{o}$, femoral anteversion $\geq$ 30-35^{o} and $\geq$ 40-45^{o} of tibial external torsion.
- Always determine the site of prevailing deformity and try to correct it in that level.

Tibial tuberosity osteotomy (TTO)

- Effective in patellar realignment, correction of patellar height and shifting the load from lateral and distal patella to the medial and proximal patella.
- Isolated medial transfer has seen a drop in popularity in recent years, however TTTG $\geq$ 15-20mm on MRI with a significant glide J-sign should probably be considered for correction.
- Patellar alta with Caton-Deschamps index $\geq$ 1.3 should also be considered for distalization, especially if a significant glide J-sign is present.
- Anteromedialization (AMZ) TTO can be considered in patient with severe lateral and distal patellar chondral damage, especially if symptomatic (pain and swelling).

Trochleoplasty

- High grade trochlear dysplasia is a very important predictor of instability recurrence, failure of MPFL reconstruction and limited clinical improvement.
- Dejour types B and D with trochlear bump > 5-8 mm are the most common indications for trochleoplasty, especially if a significant clunk J-sign is present.

TTTG: tibial tuberosity to trochlear groove distance

Box 4
Essential features of imaging evaluation

Femoral angular and rotational evaluation

- Long limb standing view is the gold standard for varus-valgus alignment evaluation.
- Computed Tomography (CT) is the gold standard for the evaluation of rotational malalignment including femoral and tibial torsions. Normal values vary depending on measurement methods.
- EOS, a 3-D X-ray system, is a recent addition to alignment evaluation, but is often not available.

Tibial tuberosity trochlear groove (TTTG) distance

- Initially described for CT, but nowadays utilized on magnetic resonance (MRI) that is more frequently done is clinical practice
- Values can vary between CT and MRI, especially because of knee positioning (slight flexion in MRI and full extension in CT).
- Classic TTTG distance threshold of 20mm is somewhat controversial; values $\geq$ 15 mm on MRI are significantly abnormal ($\geq$ 2 standard deviations from the population mean).

Trochlear imaging

- Gold standard is a true lateral view radiograph and Dejour's classification, however CT and/or MRI, especially, the axial and true sagittal views are helpful in the assessment.
- Dejour's types B and D with the present of trochlear spur/bump are considered high grade trochlear dysplasia, however the size of the bump matters and is an indicative of severity.
- Always consider trochlear spur/bump magnitude regarding the anterior off-set and length: the more anterior and longer (proximal-distal), the more abnormal the patella tracking.

Box 5

Tips and tricks

The medial patellofemoral ligament (MPFL) reconstruction is the workhorse of patellar stabilization procedures and should always be included in the surgical treatment

Femoral osteotomy for patellofemoral instability

- A lateral plate is more commonly used, preserving the medial side for ligamentous reconstructions.
- In varus lateral femur opening wedge osteotomies, try to preserve the medial hinge. A K-wire introduced in the medial cortex can help prevent medial hinge fractures.
- Biplanar osteotomy offers more stability and bone surface contact for healing.
- Pre-operative planning is essential. Computer softwares with virtual planning can simulate the osteotomy as well as associated procedures. Associated procedures are very common, always plan a step-by-step approach and consider the interference one has on another.
- Positioning parallel K-wires proximal and distal to the osteotomy site helps visualizing angular and rotational corrections.
- Derrotational osteotomies are more frequently performed in the supracondylar region (distal) but can be performed in the hip or shaft as well.
- When correcting simultaneous torsional and angular deformities, oblique osteotomies can correct both simultaneously with a single cut.

Tibial tuberosity osteotomy

- The osteotomy should be at least 5cm long, allowing fixation with at least two screws. One can consider a longer shingle to allow fixation with 3 screws for distalization.
- Compression screw techniques are preferred on the osteotomy site. There is no need for screw washers.
- Increased inclination angles (anteromedial to posterolateral) mean there is increased anteriorization and less medialization.
- Avoid converting a patella alta to a patella baja. A CD index of 1.1 is probably a good goal for the correction.
- Progressive weight bearing can be allowed after the procedure with the brace locked in extension. Single leg raises can be performed with the brace. Active resisted knee extension should be delayed until there are signs of healing, usually 6 weeks.

Trochleoplasty

- Is a technically demanding procedure.
- Sulcus deepening trochleoplasty is favored over other techniques, either with a thin or thick flap.
- Fixation is recommended, either with absorbable suture/tape and anchors or headless screws.
- Aim is to bring the anterior trochlear in line to the anterior femoral cortex, eliminating the anterior spur/bump.
- Remember that the new sulcus is positioned laterally, so the TTTG is decreased. Take this into account when considering other associated procedures.
- Range of motion should be started immediately.

Box 6

Major pitfalls of osteotomies for patellofemoral instability

- Low evidence level of most studies about surgical procedures for patellofemoral instability.
- Most of the times, osteotomies are not done as single procedure. Surgeries are complex and lengthy.
- Tridimensional anatomy is difficulty to visualize and plan.
- It is difficult to predict the effect of each realignment procedure in the patellofemoral.
- There is a higher risk of arthrofibrosis with increased number of procedures, especially, if including intra-articular procedures and arthrotomy, including trochleoplasty and cartilage restoration procedures.
- Cutoffs and surgical thresholds for corrections as well as goals for correction are controversial.
- Two-stage procedures can be beneficial or necessary; specially if the rehabilitation restrictions and goals differ regarding weight bearing status and allowed range of motion.
- An experienced surgical team is very important; one cannot do it alone, you need more than 2 hands on.
- Rehabilitation is of paramount importance and must be started as soon as possible.

Box 7
Future perspectives

- Future clinical studies are needed to improve indication criteria for each procedure.
- Surgical head-to-head trials are needed to standardize practice.
- Improvements on anatomy description and treatment guiding classifications can help surgeons, especially when considering the trochlear evaluation and its 3D anatomy.
- Long term follow-up or natural history studies are needed for most procedures.
- Development of dynamic evaluation methods could help practitioners understand the dynamic relationship of the PF joint in action.
- Development of tools to evaluate and improve the psychological profile; patient resilience, catastrophizing, anxiety and expectations play a role in patient outcomes. The knee lives in a patient.

PF: patellofemoral

Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Elizabeth A. Arendt reports a relationship with International Society of Arthroscopy Knee Surgery and Orthopaedic Sports Medicine that includes: board membership. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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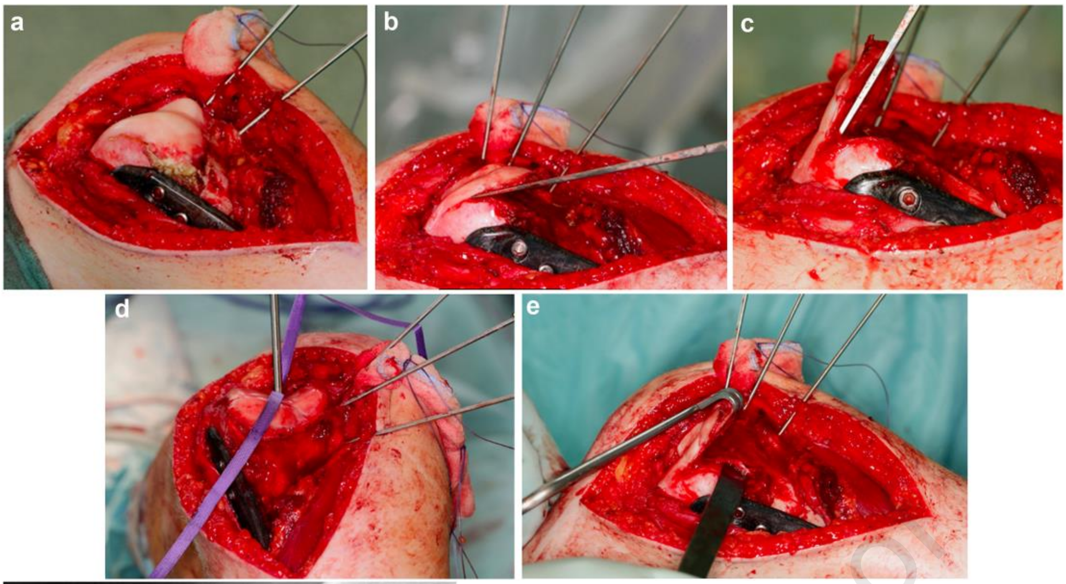
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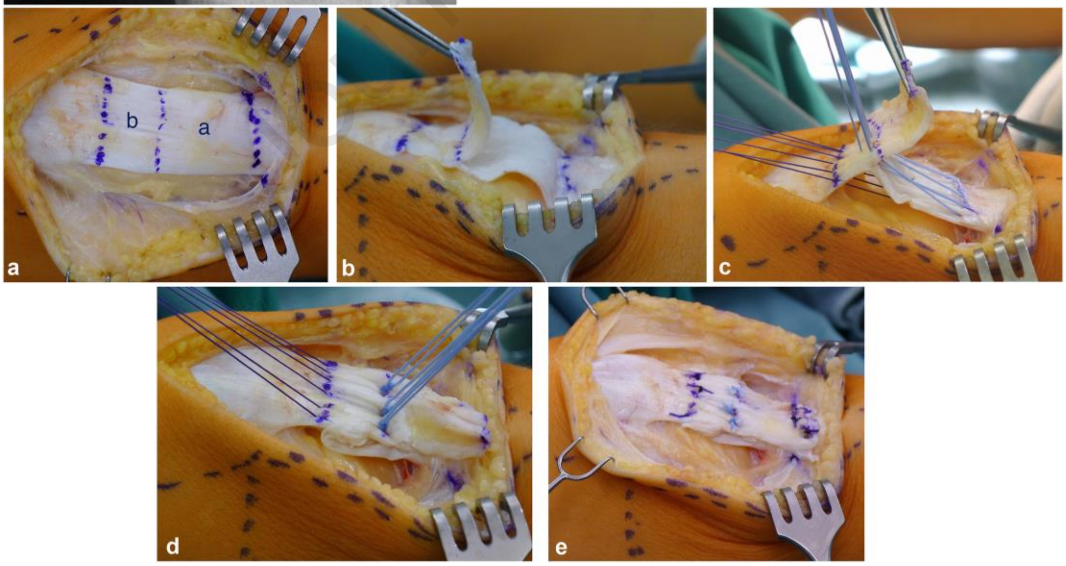
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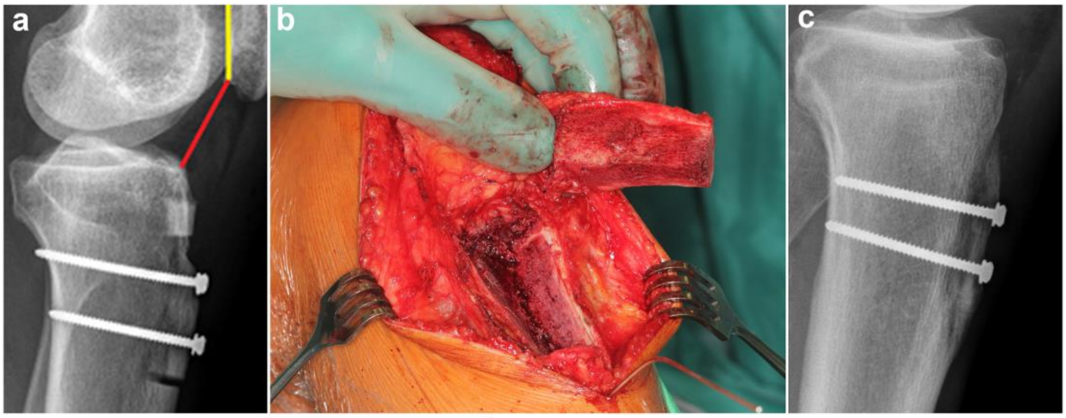
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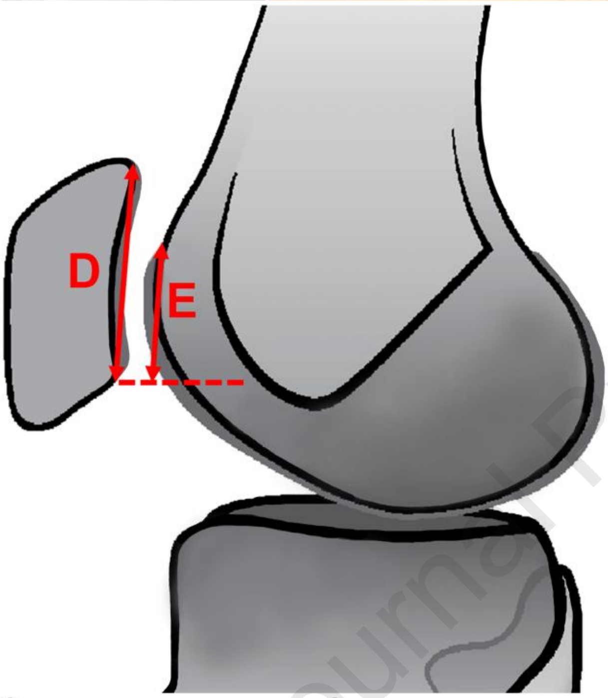
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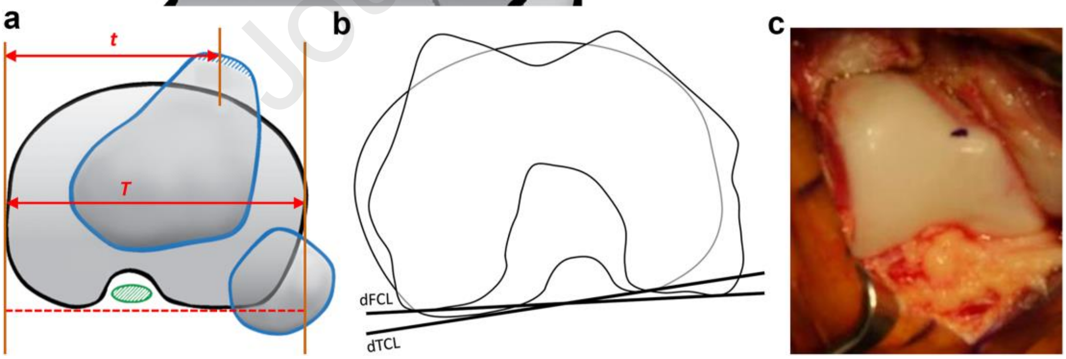
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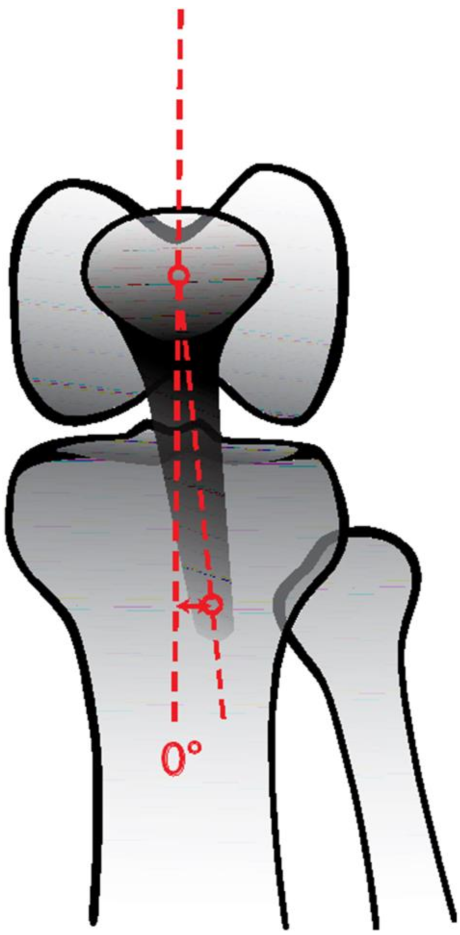
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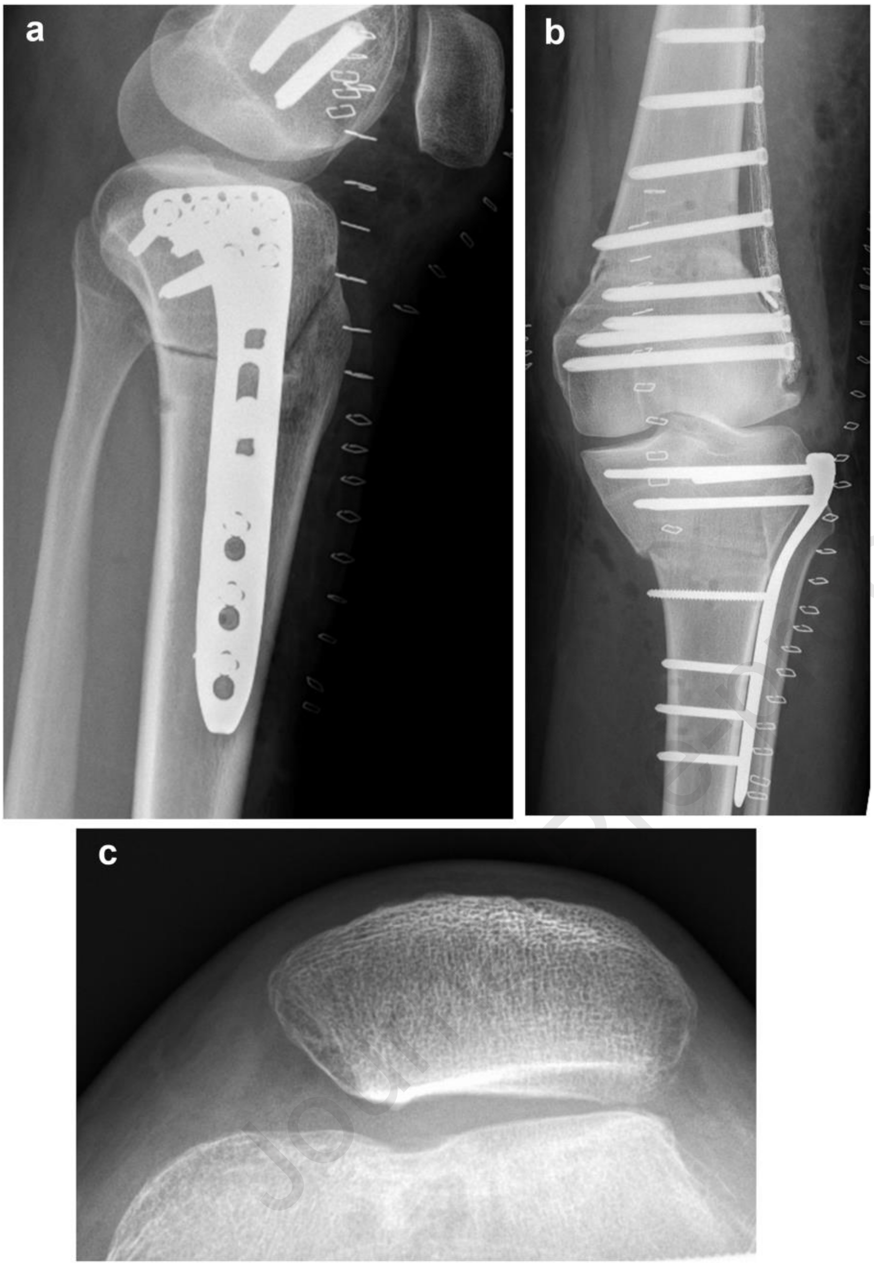
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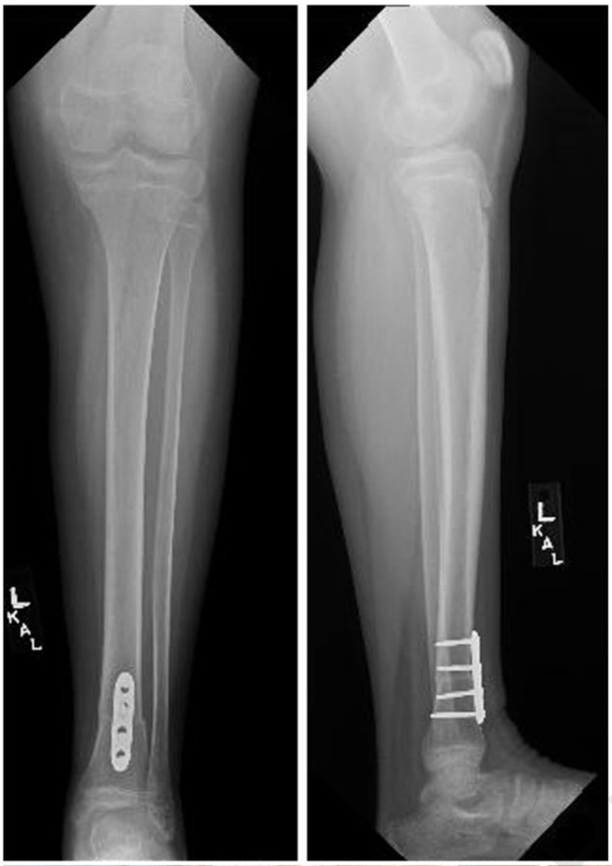

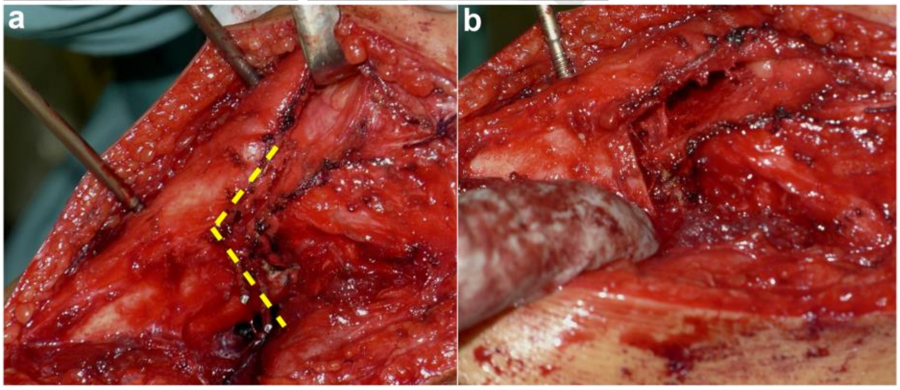
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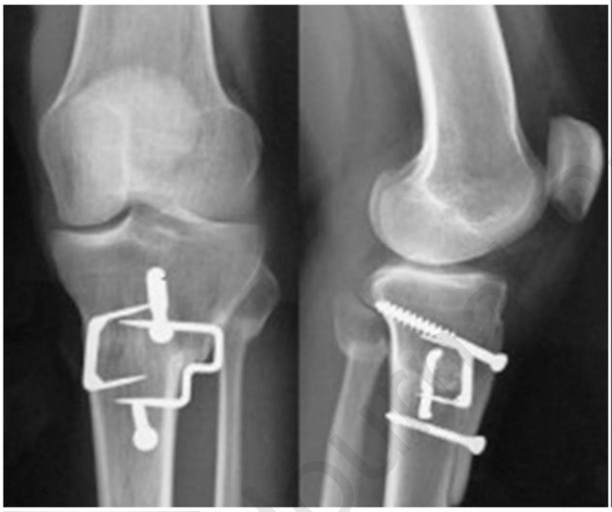

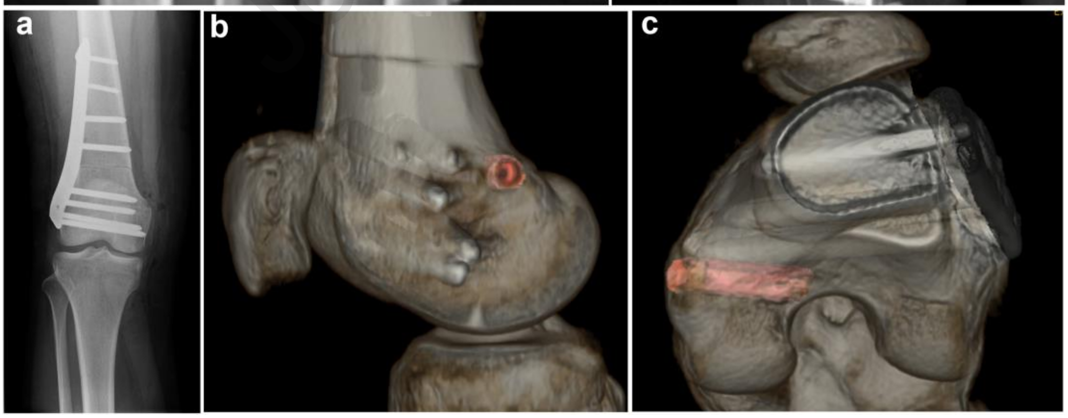
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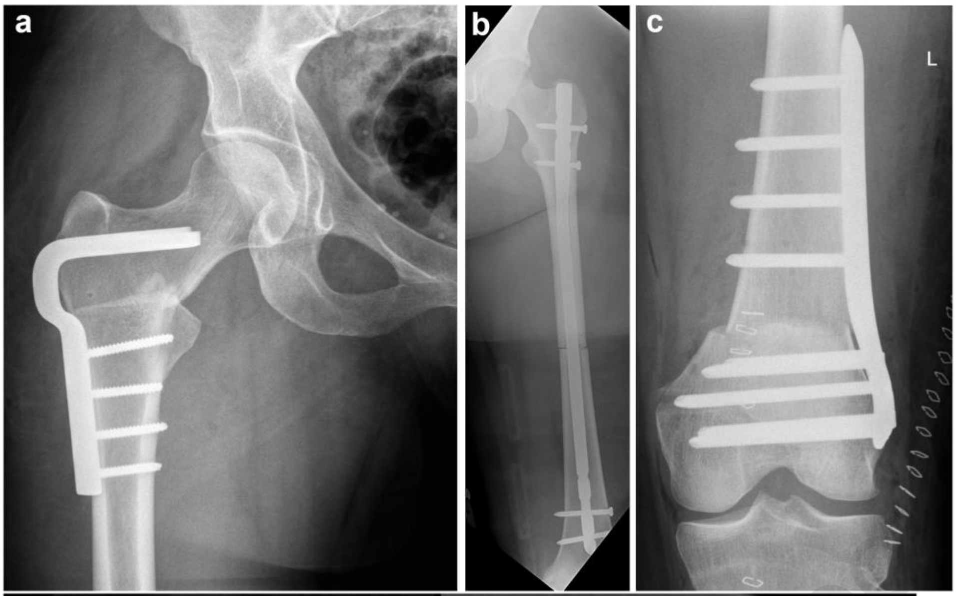
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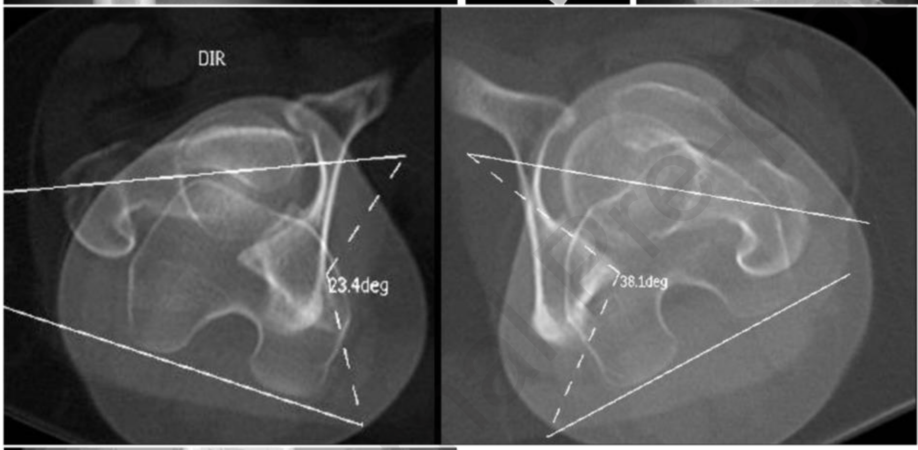
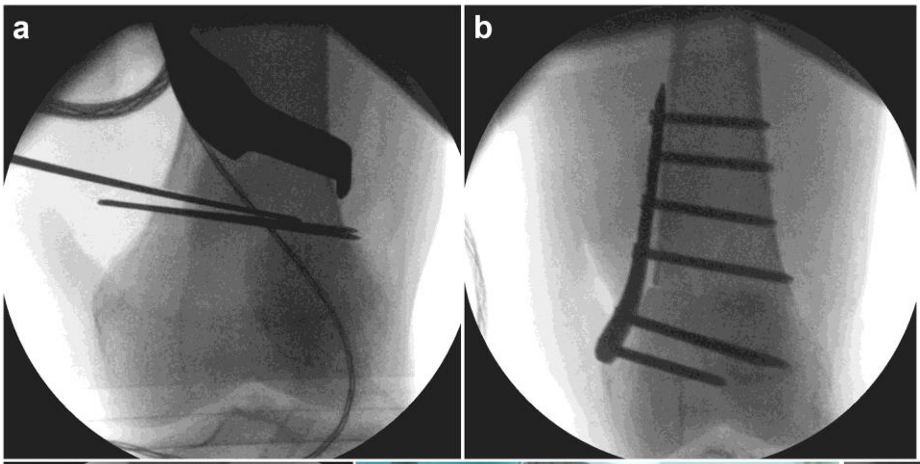

DIR
23.4deg
38.1deg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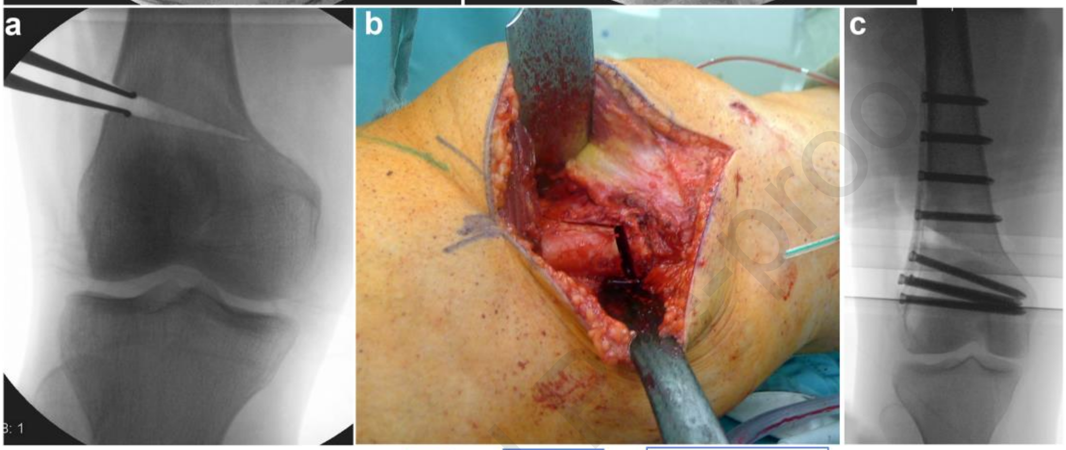
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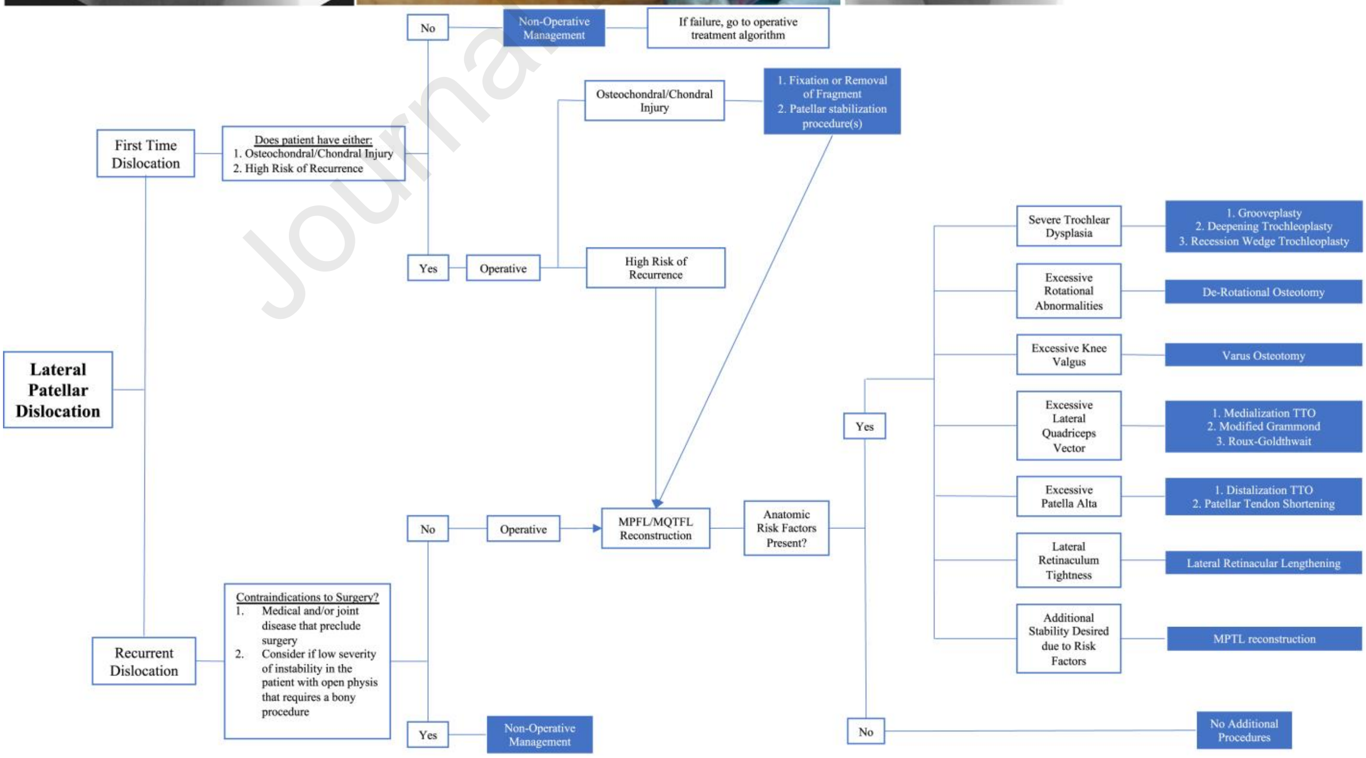
Lateral Patellar Dislocation
First Time Dislocation
Does patient have either:
1. Osteochondral/Chondral Injury
2. High Risk of Recurrence
No
Non-Operative Management
If failure, go to operative treatment algorithm
Yes
Operative
Osteochondral/Chondral Injury
1. Fixation or Removal of Fragment
2. Patellar stabilization procedure(s)
High Risk of Recurrence
Recurrent Dislocation
Contraindications to Surgery?
1. Medical and/or joint disease that preclude surgery
2. Consider if low severity of instability in the patient with open physis that requires a bony procedure
No
Operative
Yes
Non-Operative Management
MPFL/MQTFL Reconstruction
Anatomic Risk Factors Present?
Yes
Severe Trochlear Dysplasia
1. Grooveplasty
2. Deepening Trochleoplasty
3. Recession Wedge Trochleoplasty
Excessive Rotational Abnormalities
De-Rotational Osteotomy
Excessive Knee Valgus
Varus Osteotomy
Excessive Lateral Quadriceps Vector
1. Medialization TTO
2. Modified Grammond
3. Roux-Goldthwait
Excessive Patella Alta
1. Distalization TTO
2. Patellar Tendon Shortening
Lateral Retinaculum Tightness
Lateral Retinacular Lengthening
Additional Stability Desired due to Risk Factors
MPTL reconstruction
No
No Additional Procedures