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ADVANCES IN PATELLOFEMORAL SURGERY (L REDLER, SECTION EDITOR)

Trochleoplasty: Indications and Technique

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Abstract

Purpose of Review Trochlear dysplasia is a well-described risk factor for patellar instability. Trochleoplasty has emerged as a procedure within the surgical armamentarium for patellar instability, yet its role is unclear. A variety of trochleoplasty procedures have emerged. The purpose of this review is to clarify indications for trochleoplasty, outline the technical steps involved in performing common trochleoplasties and report the published outcomes and potential complications of these procedures.

Recent Findings Patellar instability with severe trochlear dysplasia is the main indication for trochleoplasty. Three types of trochleoplasty have emerged: (1) lateral facet elevation; (2) sulcus deepening; and (3) recession wedge. Deepening and recession wedge trochleoplasties are the most commonly performed.

Summary Trochleoplasty is a surgical option for addressing patellar instability in patients with severe trochlear dysplasia. Deepening and recession wedge trochleoplasties that address Dejour B and D dysplastic trochleas are the most studied, with both short- and midterm outcomes reported. Long-term outcomes are lacking and comparative studies are needed.

Keywords Trochleoplasty · Trochlear dysplasia · Patellar instability · Patellar dislocation

Introduction

Patella instability is a common problem, often affecting young, active patients. Unaddressed, recurrent patellar instability can lead to patellofemoral chondral damage, arthrosis, and diminished knee function. There are multiple risk factors for patellar instability including coronal or rotational limb malalignment, incompetent medial soft tissue structures, specifically the medial patellofemoral ligament (MPFL) complex, and trochlear dysplasia.

This review focuses on the emergence of trochleoplasty as a technique for addressing patellar instability associated with trochlear dysplasia. We review the described techniques and published outcomes.

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Patellofemoral Anatomy and Biomechanics

The morphology of the trochlea is important for normal patellofemoral tracking and to maintain patellar stability. A cadaveric study performed by Amis et al. demonstrated that in normal knees, the patella reliably medializes from a position 4 mm lateral to the center of the trochlea in full extension to engage the trochlear groove at 20° of flexion [1]. The patella then remains centered in the trochlea throughout the remainder of knee flexion. Patellar maltracking occurs when the patella either fails to engage or later disengages from the trochlear groove. The MPFL acts as the major restraint to lateral patellar translation from full extension through the first 20°–70° of knee flexion [2, 3]. The trochlea serves as the main restraint throughout the remainder of flexion [4]. The contribution of the MPFL to stability during the first 20° of flexion was further demonstrated in a biomechanical study which showed reduced forces required for patellar subluxation with

an incompetent MPFL [5]. This study also demonstrated that a shallower trochlear groove decreased the force required for patellar displacement throughout the entirety of knee range of motion to the same degree as an incompetent MPFL, thus highlighting the structural importance of the trochlea in maintaining normal patellar tracking [5]. A shallow trochlea is said to be dysplastic if the sulcus angle, taken on an axial radiograph with the knee flexed to 30°, is greater than 145° [6, 7].

Patellar Instability

Patellar instability results when maltracking becomes symptomatic. Authors variably define symptomatic instability as patient reported apprehension during knee range of motion, a single dislocation/subluxation event, or recurrent dislocations [6, 8–10]. A patient sustaining a first-time dislocation has a 17% chance of re-dislocating in 5 years, whereas a patient with abnormal or painful patellar motion preceding their index dislocation has a recurrence rate up to 49% [11]. Therefore, the importance of addressing patellar instability early is to prevent recurrent dislocations or subluxations, repetitive chondral damage and eventual progression to patellofemoral arthritis.

Diagnosing Trochlear Dysplasia

Trochlear dysplasia has been reported to be present in 85–96% of patients with a patellar dislocation event [6]. Therefore, a high index of suspicion should arise with a report of dislocation/subluxation or apprehension on exam [6]. A thorough physical exam implicating instability may suggest trochlear dysplasia. Specifically, the examiner can observe a J-sign or perform an apprehension test by applying a laterally directed force to the patella during knee flexion to mimic a dislocation event [12]. The apprehension test is positive if the maneuver elicits an unpleasant reaction by the patient or if the patient guards against dislocation with quadriceps contraction. Despite the high correlation of patellar instability with trochlear dysplasia, patellar tracking is influenced not only by the trochlear groove but also by the soft tissue structures about the knee, particularly the medial restraining structures A hypermobile patella does not conclusively implicate trochlear dysplasia as the cause of instability. Therefore, trochlear dysplasia requires further radiologic analysis for diagnosis.

Classifying Trochlear Dysplasia

H. Dejour used a true lateral radiograph at 30° of knee flexion to identify three patterns of trochlear flattening based on where the trochlear floor crosses anterior to the lateral condyle (represented by a crossing sign on lateral x-ray imaging) [6]. Type 1 correlates with minor dysplasia with crossover/flattening at the superior-most portion; Type 2 has crossover at the trochlear floor with asymmetric condyles (crossover first medially then laterally); and Type 3 has symmetric, but low-seated, condyles with near-total flattening and a prominent trochlear spur secondary to anterior translation of the trochlear floor (Figs. 1, 2, and 3). These patterns exist in 96% of knees experiencing a dislocation event but only in 3% of controls [6]. Dejour further identified multiple radiographic parameters that are present in trochlear dysplasia: (1) trochlear depth < 4 mm or < 3 mm on MRI; (2) patellar tilt > 20°; (3) spur height > 5 mm; and (4) trochlear angle > 145° [6, 13].

H. Dejour then incorporated findings from lateral and axial/merchant radiographs to expand the three patterns of trochlear dysplasia that he previously identified to four subtypes A–D (Table 1) [15]. These are demonstrated in Figs. 4 and 5. Despite a study demonstrating only fair inter- and intra-observer agreement, the Dejour classification has been widely accepted in the contemporary literature [14].

Trochleoplasty Subtypes

Prior to the adoption of Dejour's classification system, trochleoplasty procedures were developed to address the shallow trochlea. While the Dejour classification implicates the shallow groove, supratrochlear spur, and medial condyle hypoplasia as the hallmark features of trochlear dysplasia, this was previously unclear and some posited that dysplasia of the lateral femoral condyle was synonymous with trochlear dysplasia. Anatomical variations have led to the development of multiple trochleoplasty procedures. These include (1) lateral facet elevation trochleoplasty, which deepens the trochlear groove by augmenting the lateral femoral condyle; (2) sulcus deepening trochleoplasty; and (3) recession wedge trochleoplasty, which addresses the prominent supratrochlear spur to prevent the patella from overriding it and becoming unstable during knee flexion [17]. As these techniques all address different trochlear deformities, they are variably indicated.

Indications and Contraindications

The primary indication for a trochleoplasty includes high-grade trochlear dysplasia with patellar instability without patellofemoral arthritis and either previously addressed or absent coronal and rotational malalignment [16]. As stated above, multiple trochleoplasty procedures for the different trochlear dysplasia subtypes exist. Conventionally, Dejour B and D dysplasia are treated with deepening trochleoplasties, whereas no consensus exists for the treatment of Dejour C dysplasia [16, 18, 19]. However, a recent three-dimensional modeling study noted that a recession wedge trochleoplasty that directly addresses the trochlear spur may be best for Dejour B dysplasia, whereas Dejour C and D dysplasia are

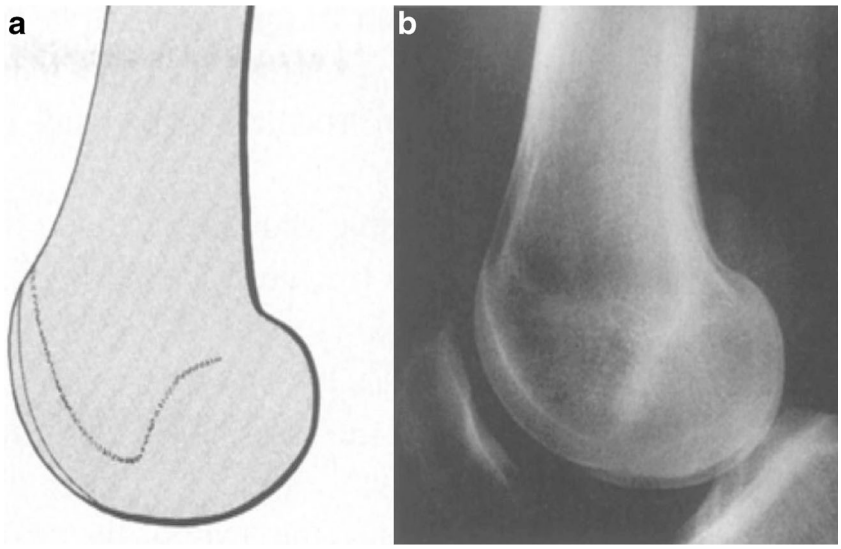

Fig. 1 Type 1 trochlear dysplasia. The crossing of the two condyles and the trochlear floor occurs symmetrically and proximally. As demonstrated by the **a** line drawing and **b** x-ray imaging [Used and adapted with permission from [6, p. 21]]

best treated by deepening trochleoplasties [20]. This study also states that lateral facet elevation is unnecessary in correcting trochlear dysplasia as it is not synonymous with lateral condyle hypoplasia, and thus this form of trochleoplasty is not indicated. As previously mentioned, intra- and inter-rater reliability is only fair when utilizing the four-grade classification. A recent study classified trochlear dysplasia into a two-grade classisifcation system: low grade (type A dysplasia) and high grade (types B–D). This showed improved intra- and inter-rater reliability when graders used either lateral radiographs or MRI (with MRI having excellent reliability) [14].

Despite the variable indications and lack of consensus for which trochleoplasty procedure to perform, there are important contraindications, including skeletal immaturity and advanced patellofemoral arthritis. Patients with open physes should not undergo a trochleoplasty until skeletal maturity [16]. Patients with advanced patellofemoral arthritis are unlikely to benefit as they already manifest the long-term complication of an incongruent patellofemoral joint. In addition, patients with patellar instability who either lack trochlear dysplasia or have low-grade Dejour A dysplasia (dysplasia with a near normal sulcus angle), are unlikely to benefit from trochleoplasty and should not undergo the procedure [16].

Trochleoplasty Techniques

Three main types of trochleoplasties are described: (1) lateral facet elevation; (2) trochlear deepening; and (3) recession wedge. Typically, these are not performed in isolation and are combined with other procedures such as bony (tibial tubercle transfers) and/or soft tissue (MPFL reconstruction, vastus medialis obliquus [VMO] plasty, lateral release/lengthening) corrections [21].

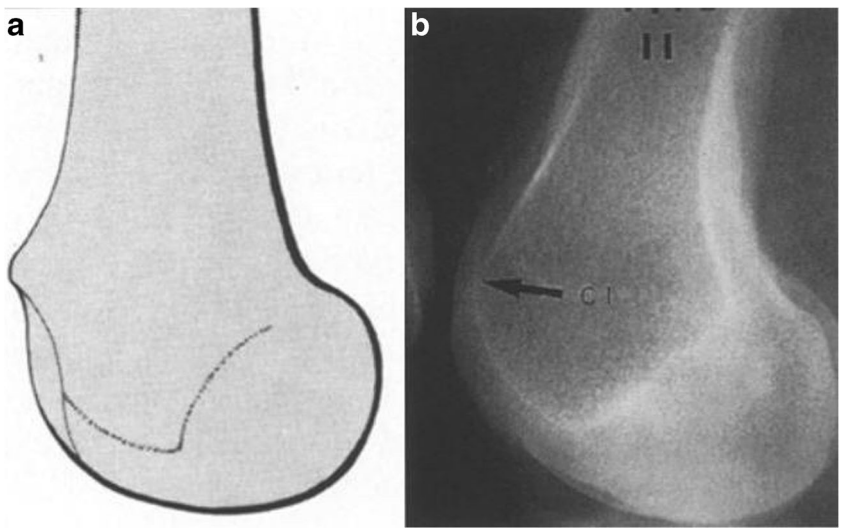

Fig. 2 Type 2 trochlear dysplasia. The crossing of the two condyles and the trochlear floor occurs asymmetrically. As demonstrated by the **a** line drawing and **b** x-ray imaging [Used and adapted with permission from [6, p. 21]]

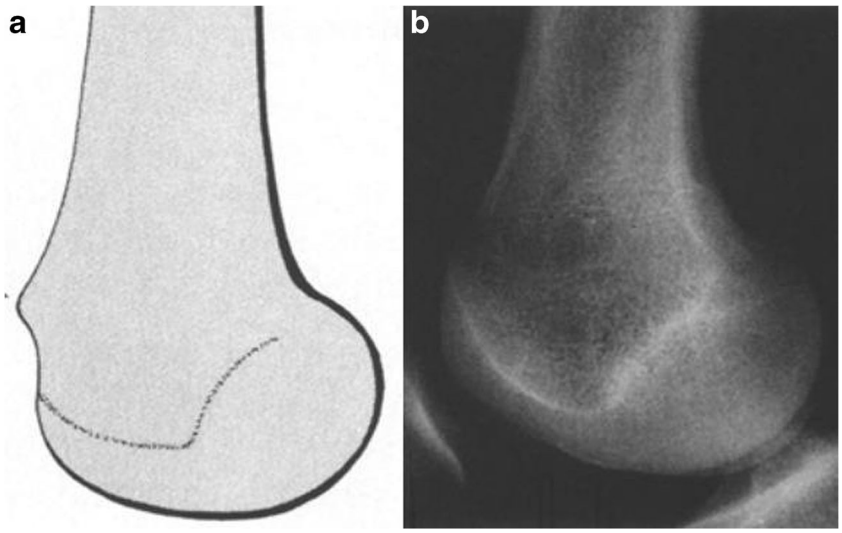

Fig. 3 Type 3 trochlear dysplasia. The crossing of the two condyles and the trochlear floor occurs symmetrically and distally. The trochlea is flat and a re-centering beak is present. As demonstrated by the **a** line drawing and **b** x-ray imaging [Used and adapted with permission from [6, p. 21]]

Lateral Facet Elevation Trochleoplasty

Albee devised a bone grafting procedure to elevate the lateral facet in order to address a shallow trochlear groove secondary to lateral condyle hypoplasia (Fig. 6) [22, 23]. This was more recently expanded upon in a chapter by Biedert [24]. He performs the procedure through a 5-cm lateral parapatellar incision. The superficial retinaculum is then incised longitudinally at distance of 1 cm from the patellar border, as it is believed to preserve the oblique portion of the retinaculum so that it can be used for lengthening, if needed. Following the arthrotomy, the patellotrochlear overlap is measured with a goal of one third in full extension. An incomplete osteotomy is made 5 mm from the cartilage of the sulcus, beginning at the cartilage edge and taken 1–1.5 cm into the condyle and proximally into the shaft. This is opened with a chisel and cancellous bone is impacted into the created space. The lateral facet is elevated by this procedure approximately 5–6 mm from the anterior femoral cortex. The retinaculum is repaired at 60° of knee flexion [24].

Table 1 Radiographic findings by Dejour dysplasia type [14]

Dejour dysplasia type	Radiographic findings
A	(1) Crossing sign
	(2) Shallow trochlea; sulcus angle > 145 on merchant view
B	(1) Crossing sign
	(2) Supratrochlear spur
	(3) Flat trochlea
C	(1) Crossing sign
	(2) Medial facet hypoplasia; double contour
D	(1) Crossing sign
	(2) Supratrochlear spur
	(3) Double contour
	(4) Cliff between medial and lateral facets

Sulcus Deepening Trochleoplasty

Currently two main types of deepening trochleoplasty procedures exist: sulcus deepening and Bereiter deepening.

The sulcus deepening trochleoplasty was devised in 1987 by Dejour as a modification of the pre-existing deepening trochleoplasty described by Masse in 1978 [16, 25]. A medial parapatellar arthrotomy with a modified midvastus approach is used. The patella is everted to inspect the chondral surfaces and then retracted laterally. Peritrochlear synovium and periosteum are reflected using a periosteal elevator for full exposure of the trochlea. The desired new trochlear groove is marked from the intercondylar notch towards the osteochondral edge (which is located 3°–6° proximally and laterally) [16]. The lateral and medial facet limits at the condylotrochlear grooves are then identified and marked. Subsequently, a sharp osteotome and a rongeur are used to remove a strip of cortical bone from the proximal osteochondral edge of the trochlea allowing access to the cancellous bone beneath it. A drill with a 5-mm depth guide is used to remove cancellous bone from the undersurface of the trochlea, preserving subchondral bone stock. A scalpel is used to sharply incise the osteochondral flap at the midpoint of the newly desired groove. The articular bone flap is then molded to the new underlying cancellous surface. A staple is traditionally used to fix each side of the trochlea to its new groove, however, countersunk or headless metallic screws as well as bioabsorbable screws have been described [26]. The peritrochlear synovium and periosteum are typically sutured to the osteochondral edge and anchored with staples [16] (Fig. 7)

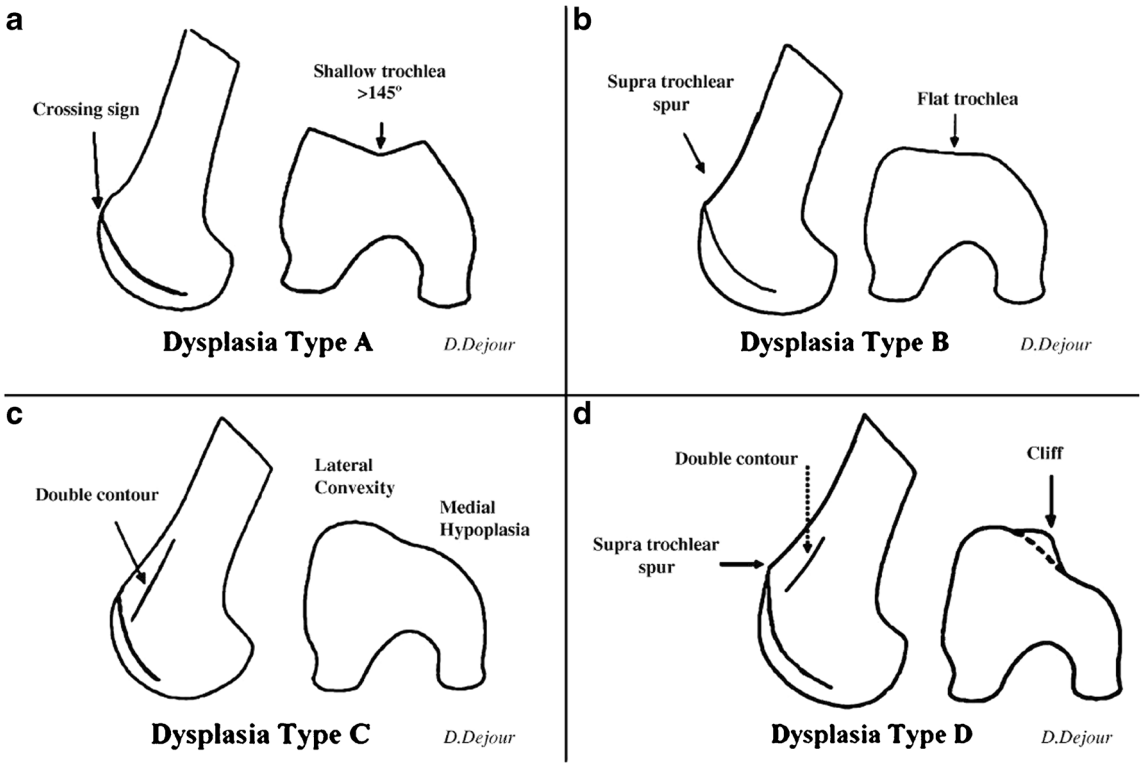

Fig. 4 **a** Type A dysplasia is characterized by a shallowed yet concave trochlea with a crossing sign indicative of trochlear flattening. **b** Type B dysplasia has a flattened or convex trochlea with a resultant supratrochlear spur that attempts to prevent patellar dislocation. **c** Type C dysplasia has a convex lateral trochlear facet and medial facet hypoplasia with a double contour on lateral x-ray imaging due to subchondral sclerosis at the medial condyle. **d** Type D dysplasia has a cliff pattern to its trochlear fossa in addition to imaging findings of a double contour, crossing sign and supratrochlear spur. [Used and adapted with permission from [16]]

Subchondral Deepening Trochleoplasty

The Bereiter subchondral deepening trochleoplasty is performed in a similar fashion to Dejour's technique but may be accessed through a direct midline or a superolateral/lateral parapatellar approach. A 3–5-mm osteochondral flap is elevated from the whole of the trochlea creating a "cartilage flake" or "thin flap" with a sharp osteotome. This allows for a concave-shaped flap that more closely approximates the normal trochlear shape than the V-shaped trochleoplasty created by the Lyon's technique sulcus deepening trochleoplasty. While this may help patellar tracking, theoretical risks include chondrocyte death and flap necrosis, although there are few reports of this occurring. The subchondral bone is removed with a burr, followed by deepening of the groove with a burr to allow a contoured groove. The removal of subchondral bone from the cartilage flap allows for it to plastically deform to the newly shaped groove. The flap is then fixed with sutures or suture anchors (Fig. 8) [17, 27, 28].

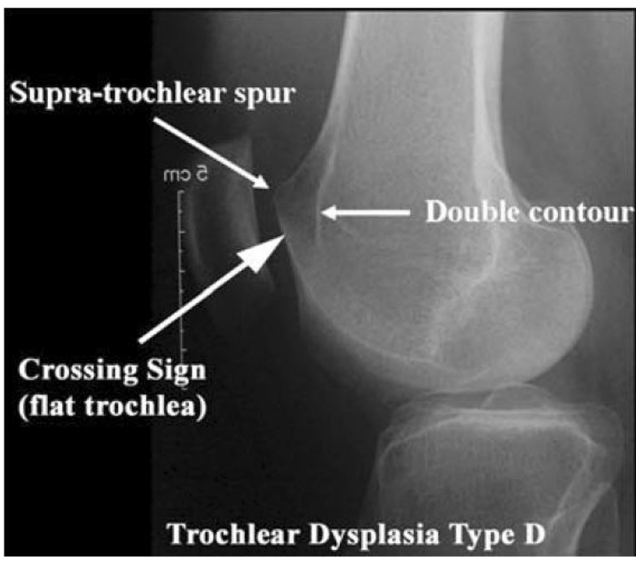

Fig. 5 Lateral x-ray imaging of Type D trochlear dysplasia demonstrating its three characteristic features: (1) the crossing sign, (2) a supratrochlear spur, and (3) a double contour. [Used and adapted with permission from [16]]

Arthroscopic Deepening Trochleoplasty

Blond and Schöttle have applied the Bereiter technique arthroscopically. A tourniquet is first applied to the thigh and a standard diagnostic arthroscopy is performed to establish trochlear geometry and for chondral inspection prior to trochleoplasty. Under direct visualization through the lateral portal, superomedial and superolateral portals are developed

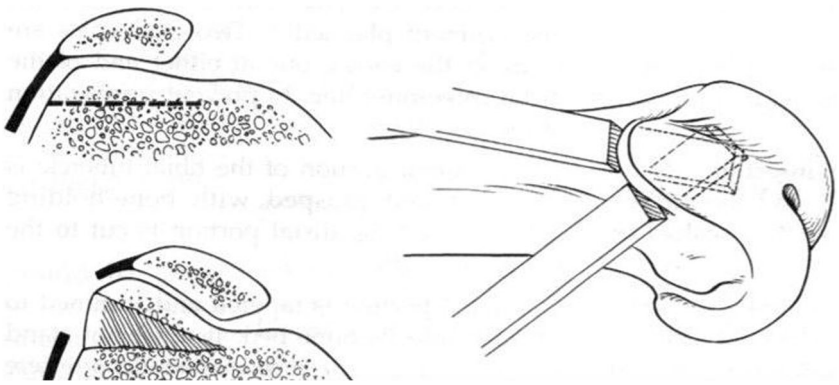

Fig. 6 Lateral Facet Elevation Trochleoplasty. [Used and adapted with changes to the figure legend from [22] http://creativecommons.org/licenses/2.0]

through the suprapatellar bursa. The arthroscope is placed through the superomedial portal and the superolateral portal is expanded to 8.25 mm. An additional lateral portal is made proximal to the lateral trochlear border, expanded to 5.75 mm and visualized synovial tissue undergoes radiofrequency ablation to expose cortical bone. A 4-mm round burr elevates a thin flap. The trochlear groove is then deepened and the supratrochlear spur is removed. The cartilage flap is then plastically molded to the new groove and fixed with four 3.5-mm suture anchors: the first of which is placed distal to the cartilage flap through a medial portal with the next three placed proximally through a stab incision made just medially to the patella [17, 29, 30].

Recession Wedge Trochleoplasty

Trochleoplasty by means of a retrotrochlear recession wedge osteotomy was devised by Goutallier in 2002 and has been further reported on by Thaunat and Beaufils [31]. As with other trochleoplasties, the patient is positioned supine. Here, the skin incision is made lateral to midline centered over the tibial tubercle and extended proximally along the lateral border of the patella and distally towards the anterior tibia. The lateral retinaculum and synovium are sharply released. The osteotomy is marked out and an anteroposterior cut is made, 5 mm above the trochlea, using a reciprocal saw. The posterior cut is then made parallel to the coronal plane in a lateral to

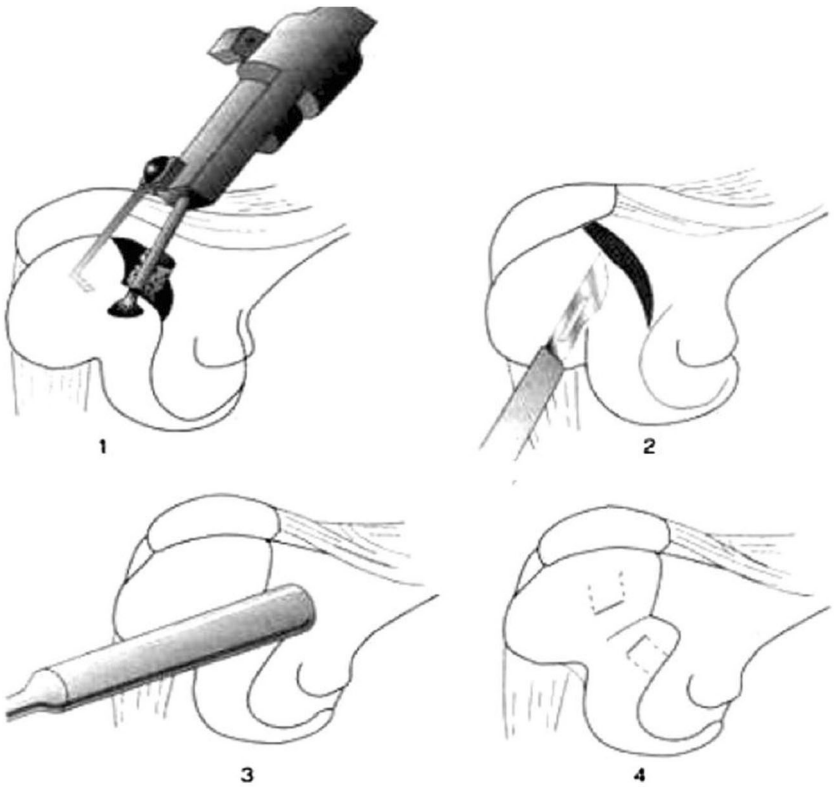

Fig. 7 Sulcus deepening trochleoplasty. The patella is first everted laterally after a medial parapatellar/midvastus approach. Then, a segment of cortical bone is removed from the proximal aspect of the trochlea, followed by removal of underlying cancellous bone with either a burr or drill. The trochlea is then sharply incised to allow for creation of a V-shaped flap. The flap is then molded to the newly shaped trochlea. Staples are placed at the periphery of the groove to fix the flap in place. [Used and adapted with changes to the figure legend from [22] http://creativecommons.org/licenses/2.0]

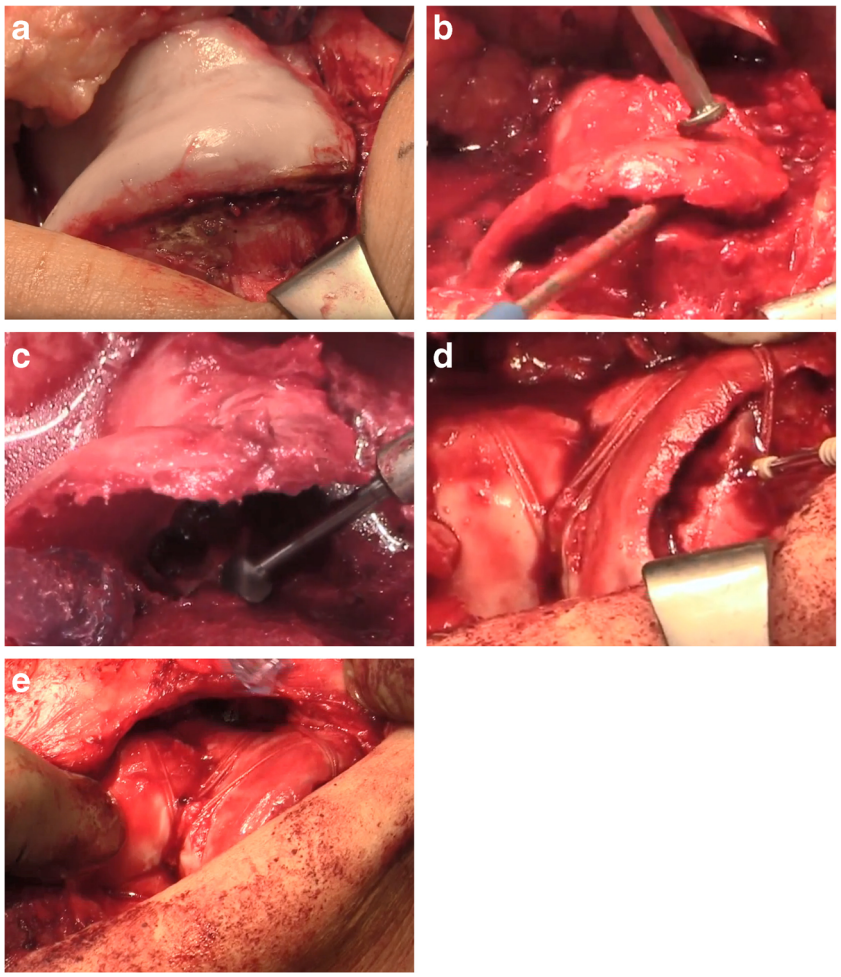

Fig. 8 Subchondral deepening trochleoplasty. **a** Exposure of the trochlea, medial, and lateral femoral condyles with retraction of overlying soft tissues after a lateral parapatellar approach. **b, c** Subchondral deepening after initial osteotomy and raising of the osteochondral flap. **d, e** Suture anchor fixation of the thin osteochondral flap [intraoperative photos courtesy of Laith M. Jazrawi, MD]

medial direction ending 5 mm from the sulcus terminalis to preserve a distal osteochondral hinge. An anterior slanting cut then joins the first two cuts. The osteotomized bone is removed and the wedge is closed manually. Two vs three 3.5-mm cancellous screws (two lateral screws with or without one medial screw) are countersunk into the bone to secure the recessed wedge (Fig. 9) [22, 31].

Outcomes

Recent short and midterm trochleoplasty follow-up data is conflicting. Most studies demonstrate improvements in patients' functional outcomes and decreased instability events. However, many patients report continued pain and have variable perceptions of satisfaction.

Functional results are available for all types of modernly performed trochleoplasties. In their modification of Albee's lateral facet elevation trochleoplasty, Koeter and Pavkis' patients experienced no re-dislocations and improvements in functional outcomes [32]. For Dejour, Bereiter, and arthroscopic deepening trochleoplasties, multiple studies have demonstrated statistically significant improvements in the Kujala score for patellofemoral pain, International Knee Documentation Committee (IKDC) scores, visual analog scores (VAS), and patient satisfaction ratings [18, 33–36, 30·]. However, Thaunat et al. found that functional improvements only trended towards, but did not reach, statistical significance after recession wedge trochleoplasty [31]. These results are similar for both open and arthroscopic procedures as well as for those performed concomitantly with other bony and/or soft tissue corrections [28–30, 36].

Importantly, most studies reported no patellar re-dislocations at final follow-up [28, 32, 33, 35–39). Notably, in the arthroscopic-deepening group, 10% (3/29) of patients developed subluxation requiring reoperation; however, there were no dislocations [30].

Not all results have been as positive. In Dejour and Saggin's description of their trochleoplasty technique, only 65% of those undergoing a deepening trochleoplasty for revision surgery were satisfied at 6-year final follow-up, whereas 85% of those undergoing primary correction were satisfied by 7 years. Another study reviewing results after 18 months noted 7 patients scored poorly on the Larsen-Lauridsen scale indicating pain, stiffness, crepitus, range of motion and

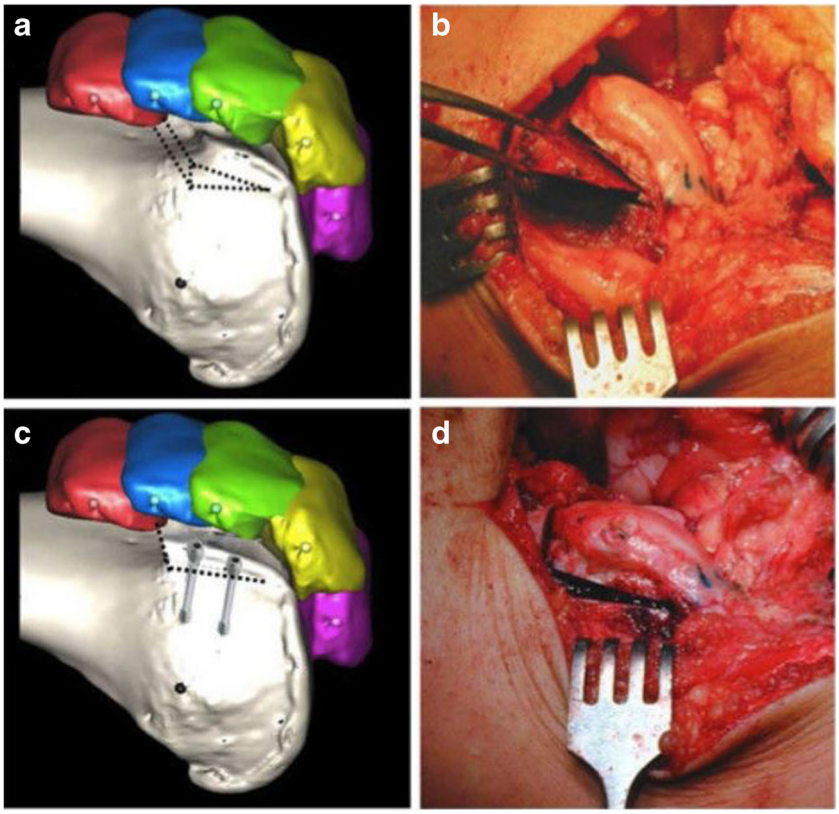

Fig. 9 Recession wedge trochleoplasty. **a** Preoperative planning, where the base of the wedge is measured to be the same in millimeters as the trochlear bump to allow for deepening of the trochlea without affecting the groove. **b** Intraoperative wedge resection. **c** imaging and **d** intraoperative photo demonstrating recession of the trochlea and cannulated screw fixation with screw placement lateral to the cartilage surface [Used and adapted with changes to the figure legend from [22] http://creativecommons.org/licenses/2.0]

functional impairment with only a 77% subjective satisfaction rate [37]. The mixed subjective satisfaction ratings are not atypical, as pain after trochleoplasty is a described outcome [18, 30, 32, 38, 39].

The aforementioned retrospective study results are supported by a prospective study conducted by Utting et al. In their study of 59 knees undergoing deepening trochleoplasty, they found significant improvements in all functional outcomes scores (Oxford knee, WOMAC, IKDC, Kujala, Lysholm) with a mean follow-up of 24 months. No patients had recurrent instability and 8 patients had residual pain [40].

Complications

The main complications associated with trochleoplasty are superficial wound healing complications, deep vein thrombosis, and deep infection. Additionally, complications including arthritis, stiffness/ arthrofibrosis, and recurrent dislocation have been reported. While necrosis, chondrolysis and nonunion of the trochleoplasty flaps are of concern, no studies document this outcome.

Not all studies have demonstrated complete resolution of instability and dislocation after trochleoplasty. Metcalfe's 11-year series found that 27 of 199 patients required reoperation after Bereiter subchondral deepening trochleoplasty, and 16 patients experienced at least one repeat dislocation after trochleoplasty [41]. For those patients requiring reoperation for instability, a procedure aimed at addressing tibial tubercle position or soft tissue structures was selected. This suggests that performing a trochleoplasty in isolation may not be adequate for addressing patellar instability secondary to trochlear dysplasia and concomitant procedures must also be considered.

Verdonk et al. identified five patients in their series that developed arthrofibrosis and postoperative stiffness after trochleoplasty [37]. As previously discussed, patients have a variable pain experience postoperatively and at long-term follow-up, one study noted that 33% of patients had increased pain compared to their preoperative state [34].

The development of arthritis is of particular concern. While histologic work by Schöttle demonstrated insignificant cartilage damage with maintained chondrocyte viability and only mild changes to the microscopic calcified layers, multiple long-term follow-up studies have identified arthritis in their postoperative populations [34, 42, 43]. In one such study, von Knoch et al. found that up to 30% of their patients had patellofemoral arthritis (> Iwano 2) at long-term follow-up, with most patients having chondromalacia at the time of their index procedure [34]. Rouanet et al. identified 65% of their patients as having > Iwano 2 cartilage changes after 15-year follow-up, with 7 patients requiring conversion to total knee arthroplasty [43·].

Conclusions/ Future Directions

Current literature implicates high-grade/severe trochlear dysplasia (Dejour B and D) in patients without patellofemoral arthritis and either corrected or absent coronal and/or rotational limb malalignment as the main indication for a trochleoplasty.

Studies demonstrate improved functional outcomes after trochleoplasty, with most demonstrating improved outcome scores and decreased instability events in both the short- and mid-term. While current literature demonstrates osteoarthritis progression in knees already with pre-existing degenerative changes, literature analyzing long-term progression in non-arthritic knees does not exist.

Further, studies directly comparing sulcus deepening trochleoplasty with a thick flap and subchondral deepening trochleoplasty with a thin osteochondral flap are needed. Current studies posit that too thin of a flap may result in necrosis of the flap due to vascular insult; however, no studies document an occurrence of this.

Certainly, the published literature demonstrates promising results with surgeons who regularly perform trochleoplasty. However, future studies are needed to define meaningful outcomes, determine long-term effects and standardize the procedure.

The results of existing systematic reviews have not compared isolated trochleoplasty to other surgical interventions, as no primary studies making this comparison exist. In fact, prior works state that surgeons should not perform trochleoplasty as an isolated procedure, owing to concomitant medial soft tissue damage and/or tibial tubercle malposition.

Compliance with Ethical Standards

Conflict of Interest Patrick C. Schottel reports personal fees from CD Diagnostics, outside the submitted work. The other authors declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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