Review

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Distal femur varus-producing osteotomy: An updated review of patellofemoral implications and clinical outcomes

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Abstract

Background: Recent evidence seems to suggest the effectiveness of distal femur varus osteotomy in the management of patellofemoral instability in the setting of genu valgum. However, literature on this subject remains scarce and consists mostly of small case series. **Hypothesis:** This study aims to systematically review the literature on varus-producing distal femur osteotomy and critically analyze its implications on patellofemoral kinematics and stability. **Results:** The statistical analysis revealed that this surgery is able to restore a mechanical angle (mean hip–knee–ankle (HKA): 0.22°) and to improve the main clinical outcomes (Kujala score, Knee injury and Osteoarthritis Outcome Score, visual analog scale) after a mean follow up of 2.5 years. An objective of the present review was to investigate the mechanical implications of femoral osteotomy on the patellofemoral biomechanics. Indeed, the statistical analysis demonstrated changes after surgery in the main patella-femoral radiological angles (modified Insall–Salvati index, Caton–Deschamps index, Blackburne–Peel index). Interestingly the overcorrection of the mechanical axis (HKA), resulting in varus, had similar outcomes compared to studies that obtained a mechanical axis. **Level of Evidence:** Level II study.

Keywords

Distal femur osteotomy, patella, instability, kinematics, outcome

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Introduction

Patellar stability is the result of the complex interplay between several anatomical and biomechanical factors including overall limb alignment, femoral valgus, trochlear dysplasia and dynamic balancing of forces acting at the patellofemoral interface.[1] When one or more risk factors are present patellofemoral kinematics may be altered and patellar maltracking or instability may result, possibly leading to anterior knee pain or lateral patellar dislocation.[2,3] In this context, despite the debate concerning its clinical utility, the fundamental principle of an altered force vector acting on the patella influenced the development of surgical strategies to improve patellar tracking.[4] Based on the assumption that the correction of an excessive Q-angle in genu valgum could reduce the lateral vector applied to the patella,[5] distal femur varus-producing osteotomy was postulated to be an effective option in the treatment of patellar instability associated with a valgus deformity.[6,7] Several recent studies reported on patients with valgus malalignment and patellofemoral symptoms and showed reliable patellar stabilization after distal femoral varus osteotomy.[1,4,6,8–11]

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While distal femur varus osteotomy seems to be clinically effective in the management of patellofemoral instability associated with genu valgum, the exact mechanisms for this are unclear and detailed biomechanical implications of femoral osteotomy on the patellofemoral biomechanics are just starting to be elucidated.[12,13] Moreover, literature on this subject remains scarce and consists mostly of small case series. The aim of the present study is to pool the evidence from the existing studies in order to elucidate the biomechanical implications and clinical outcomes of distal femur varus osteotomy for patellar instability in the setting of genu valgum.

Data source and studies selection

An extended research on PubMed, Google Scholar, and Embase was performed by two independent authors (FMG and GR) using various combinations of the following keywords: "Femoral distal osteotomy", "Valgus correction", "Varus osteotomy", and "Femoral osteotomy". A total of 167 related articles were identified through databases searching. After title screening and abstract reading 39 studies were included based on the following inclusion criteria: the osteotomy was performed at the level of the distal femur, bone alignment by a varus-producing osteotomy as surgical indication, English language, and clearly reported outcomes. Ultimately, a total of 16 studies published from 2005 to 2020 dealing with distal femur osteotomy and its femoropatellar implications were included in the present review.

Surgical indications

The studies included in this review had very heterogeneous objectives to evaluate the efficacy of femoral osteotomy. Seven studies[14–18] were conducted to evaluate the efficacy of femoral osteotomy on patellar tracking and clinical improvement in patellar instability.

Four studies were carried out to evaluate the clinical efficacy of the treatment: two of these studies[18,19] were carried out in young patients on non-arthritic knees, one study[15] was carried out to evaluate clinical efficacy and pain relief in arthritic knees, one study[13] instead considered a more heterogeneous cohort of patients. The aim of two studies[20,21] was to evaluate patellofemoral symptoms and the implication of femoropatellar osteoarthritis following DFO. One study[21] performed an analysis of changes in patella height following DFO, while another retrospectively evaluated postoperative axis changes without correlating to clinical outcomes. The correlation between osteotomy correction angle and its influence on Q-angle was instead investigated in another study.[22] Details of the inclusion and exclusion criteria are described in Table 1.

Surgical techniques

Concerning the surgical technique, the studies have reported different methods.

Seven studies[14–18] reported a medial closing wedge as surgical technique associated or not with a medial reefing and a lateral release.

Five studies[1,9,10,13,15] described a lateral opening wedge as a method to restore the desired axis. Also, in this case a lateral release was described in cases where this procedure was deemed necessary. One study[22] described a single-cut distal femoral osteotomy that enables concurrent correction of angulation and translation. Another study[3] used three-dimensional models obtained using patient computed tomography data and subsequently biplanar supracondylar osteotomies were simulated with different degrees of varus correction (from 1° to 15°) in one-degree steps beginning from the preoperative valgus deformity, resulting in a total of 150 simulations in order to evaluate the association between Q-angle and femoral osteotomy. Details concerning the surgical techniques are described in Table 2.

Results

Patients demographics

Sixteen studies involving a total of 235 patients and 276 knees who performed a femoral distal osteotomy for valgus deformity of the lower limb have been included in this review. All 16 studies are case series with level of evidence of IV. Concerning the patients' demographic of the latter studies, of the 227 patients 146 were females and 81 males, the mean age was 37.5 (range: 21–63.5) and the mean body mass index 27.6. Patients were followed up for a mean of 37.9 months after surgery (range: 16–99).

Radiological outcomes

Of the 16 trials, 4 studies[1,3,13,18] analyzed only radiological outcomes, the others also considered functional outcomes. The radiological outcomes taken into consideration were both related to alignment of the entire lower limb as the hip–knee–ankle angle (HKA), the lateral distal femoral angle (LDFA), femoral shortening (FS), and to the patellar alignment as the modified Insall–Salvati index (mSI), modified Caton–Deschamps index (CDI), and modified Blackburne–Peel index (BPI). Ten studies investigated the HKA, described in Figure 1, reporting an average preoperative value of 12.02° of deviation from the mechanical axis, and a mean postoperative value of 0.22°, hence an improvement of 11.80° in the HKA axis. Ten studies reported the LDFA, describing an average preoperative value of 83.4°, and a mean postoperative value of 88.3°, hence an improvement of 4.9° in the LDFA. Five studies investigated the FS, reporting an average postoperative value of 4.3 mm of FS. Concerning the patellar radiological outcomes, three studies reported the mSI (Figure 2), describing an average preoperative value of 1.11°, and a mean postoperative value of 1.13°, hence a change of 0.02° in the mSI. Three studies reported the CDI, describing

Table 1. The details about the inclusion and exclusion criteria of the studies in the present review.

	Valgus deformity	Age	Osteoarthrtis	Patellar instability	Exclusion criteria
Abdi (2017)	Mechanical tibiofemoral angle: average 16° (range: 10–23°); mechanical lateral distal femoral angle: 73° (range: 67–78°); intermalleolar distance: more than 10 cm	/	/	/	Severe collateral ligament instability, unstable knee, sagittal plane deformity (fixed flexion deformity >20° or genu recurvatum), osteoarthritis, osteomalacia, multiple epiphyseal dysplasia, or renal disease
Akaoka (2020)	/	/	/	/	/
Bavarnon (2019)	>5° of valgus deformity	65 years of age or under	Symptomatic PFO (stage I to III Iwano). Symptomatic LTFO (stage I to III Ahlbäck)	/	Ahlbäck stage I upper medial tibiofemoral osteoarthritis, inflammatory arthritis of the knee and/or an MRI-documented injury to the cruciate ligaments
Chang (2017)	Mechanical tibiofemoral angle: > 6–8° 60% Mikulicz line mechanical lateral distal femoral angle: < 86°	/	/	Cronic patellar instability	/
Elattar (2016)	Lateral knee pain and genu valgum deformity	/	/	/	Severe osteoarthritis, multiple osteophytes, and joint line obliquity
Flury (2020)	/	/	/	/	/
Frings (2018)	Relevant valgus deformity of the leg axis	/	/	≥ 2 dislocations	Higher grade deformities (types 3e and 4 according to Frosch et al.)
Frings (2018)	/	/	/	/	Open epiphyseal plates, first-time traumatic patellar dislocations (with or without flake fracture), direct trauma to the patella, complex traumas to the knee with ligament injury or traumatic knee dislocations
Kolb (2018)	MAD < 10 mm combined with a mLDFA < 88°	/	/	/	Patients with any known neurological or metabolic disorder potentially affecting knee function or bone healing
Nha (2018)	Mechanical tibiofemoral angle: >2 valgus; mechanical lateral distal femoral angle: <86°	/	/	2 episodes of dislocation or 1 episode of dislocation plus multiple episodes of instability	/
Omidi-Kashani (2009)	Intermalleolar distance >5 cm Mechanical tibiofemoral angle > 12°	/	/	Yes	Severe arthritis of the medial compartment of the knee, severe tricompartment osteoarthritis, and tibiofemoral subluxation >1 cm
Swarup (2017)	Symptomatic genu valgum deformity was defined as the presence of lateral knee pain	/	/	History of patellar subluxation or dislocation, or findings of patellar instability on physical exam or preoperative radiographs	/
Wang (2005)	Mechanical tibiofemoral angle ≥12°	/	Lateral compartment arthritis of the knee associated with a valgus deformity	/	Severe arthritis of the medial compartment of the knee, severe tricompartmental osteoarthritis, and tibiofemoral subluxation

(continued)

Table 1. (continued)

	Valgus deformity	Age	Osteoarthrtis	Patellar instability	Exclusion criteria
Wilson (2018)	Mechanical lateral distal femoral angle <85°	/	/	Recurrent traumatic patellar instability	<3-year follow up, congenital or habitual patellar instability, osteotomy indicated for pathology other than patellar instability, osteotomy in combination with other patellar-stabilizing procedures, or biplanar osteotomies
Yoshvin (2015)	Valgus deformity of the knee > 6°	/	/	Congenital patellar dislocation	Patients who had received prior conservative or surgical treatment
Zarrouck (2019)	Symptomatic valgus knee	/	/	/	/

LTFO: lateral tibiofemoral osteotomy; mLDFA: modified lateral distal femoral angle; MRI, magnetic resonance imaging; PFO: patellofemoral osteoarthritis.

an average preoperative value of 1.02°, and a mean postoperative value of 0.87°, hence a change of 0.15° in the CDI. Three studies reported the BPI, describing an average preoperative value of 0.89°, and a mean postoperative value of 0.8°, hence a change of 0.09° in the BPI.

Clinical outcomes

Knee function was evaluated using the following items: the Kujala score and the Knee injury and Osteoarthritis Outcome Score (KOOS). Indeed, 5 studies investigated the Kujala score, describing an average preoperative value of 47.08, and a mean postoperative value of 82.84, hence a change of 35.76 in the Kujala score. Four studies reported the KOOS, describing an average preoperative value of 58.17, and a mean postoperative value of 86.4°, hence a change of 28.23 in the KOOS. Of the 16 trials, 4 studies[131813] analyzed only radiological outcomes, the others also considered functional outcomes. The details of the study design and patient population of all the studies are reported in Table 1. Knee pain was evaluated using visual analog scale (VAS). Knee function was evaluated using the following items: KOOS, Tegner activity scale, Lysholm knee function score, Oxford knee score, Short Form-36 Health Survey, the International Knee Documentation Committee (IKDC), Kujala score, the Knee Society score, American Academy of Orthopedic Surgeons LLM, Hospital for special surgery knee score. The radiological outcomes taken into consideration were both related to alignment of the entire lower limb as the HKA, LDFA, medial proximal tibial angle (MPTA), tibial posterior slope (TPS), but also related to the patellar alignment as the mSI, CDI, and BPI. Only 3 studies[4,15,23] reported clinical data concerning pain on the VAS and a decrease from a mean preoperative value of 4.7 to 2.1 was observed. Kujala score was reported by 7 studies[4,14,15,16,17,19,23] reporting an average increase of 35.8 points from a preoperative mean value of 47.1 to 82.8 postoperatively. Only the study by Abdi et al.[20] uses the IKDC and reports an improvement of 6 points from 65 to 71. KOOS was used by three authors[10,15,29] with a mean improvement of 16.7 points, from 60 to 76.5. Regarding patellar outcomes, the literature is not homogeneous in its evaluation and therefore this review is limited to a descriptive analysis of the various outcomes. Akaoka et al.[1] reported that medial closed-wedge DFO for the valgus knee does not adversely affect the patellofemoral joint. Few studies[17,19,20] shows that distal femoral varus osteotomy is a valid treatment to obtain a centralization of the trochlea and a medialization of the patella. Several studies[10,18,19,21] reported the postoperative clinical outcomes of the knee without, however, specifying the recurrence rate of patellar dislocation, highlighting an improvement in the clinical parameters taken into consideration. Other studies have analyzed the recurrence rate of postoperative patellar dislocation: Frings et al.,[4] Swarup et al.,[15] and Yoshvin et al.17 did not observe redislocation of patella after surgery while Wilson

Table 2. The different techniques employed.

	Medial closing wedge	Lateral opening wedge	Medial reefing and lateral release	Biplanar/monoplanar	Plate	Other
Abdi (2017)	-	-	±	Monoplanar	Distal lateral anatomical locking plate with 3 to 4 locking screws on each side of the osteotomy	SCFO: closing–opening distal femoral osteotomy that corrects the valgus deformity of the distal femur while the translation of the distal fragment is done using one oblique cut
Akaoka (2020)	+	-	-	Biplanar	TomoFix medial distal femur anatomical plate	Arthroscopic evaluation was conducted prior to the osteotomy
Bavarnon (2019)	+	-	-	Monoplanar	OTIS-F® locked plate	The closing-wedge osteotomy was performed with great care so as to avoid a rupture of the lateral hinge
Chang (2017)	+	-	+	Biplanar	TomoFix medial distal femur (MDP) plate	Lateral femoral cortex was preserved
Elattar (2016)	-	+	±	Monoplanar	Locking Tomofix® plate	/
Flury (2020)	/	/	/	Biplanar	TomoFix medial distal femur plate	The osteotomies were simulated with different degrees of varus correction (from native mechanical axis up to 15°) in one-degree steps of the preoperative valgus deformity, resulting in a total of 150 simulations. For every step of varization, the three-dimensional Q-angle was measured
Frings (2018)	+	-	±	Biplanar	/	In the case of persistent maltracking and a pathologically increased TT–TG distance, the tibial tubercle was osteotomized creating a fragment of approximately 5 cm, which was then medialized
Frings (2018)	+	-	/	Biplanar	Angle stable plate system	An arthroscopical evaluation was performed at the beginning of every surgery, to evaluate patella tracking and cartilage status
Kolb (2018)	-	+	/	Monoplanar	TomoFix locking plate	In 5 selected cases, ChronOS® (Synthes, Inc) bone graft substitute was used to fill the osteotomy gap
Nha (2018)	+	-	±	Uniplanar osteotomy in 17 knees and biplanar osteotomy in 6 knees	TomoFix MDP plate or Ohtofix distal femoral ostheotomy (DFO) plate	Arthroscopic lateral release was then performed
Omidi-Kashani (2009)	+	-	±	Monoplanar	Prebent 90° dynamic-compression blade plate was inserted into the femoral condyle, parallel to the knee-joint line	A cortical or cancellous bone lag screw was inserted through the hole above the bend in the blade plate, across the osteotomy site, to provide additional stability
Swarup (2017)	-	+	+	Monoplanar	TomoFix® locking plate	The osteotomy site was grafted with allograft freeze-dried cancellous chips and grafton DBM putty
Wang (2005)	+	-	±	Monoplanar	Prebent 90° dynamic-compression blade plate	Of the 2 knees that had associated patellofemoral dislocation, 1 was treated with a proximal realignment as described by Insall and the other was

(continued)

Table 2. (continued)

	Medial closing wedge	Lateral opening wedge	Medial reefing and lateral release	Biplanar/monoplanar	Plate	Other
						treated with proximal and distal realignment procedures as described by Fulkerson
Wilson (2018)	-	+	/	Monoplanar	TomoFix distal femur locking plate	A tricalcium phosphate wedge (ChronOS DePuy, Synthes) of the appropriate size was then placed into the osteotomy
Yoshvin (2015)	+	-	+	Monoplanar	Distal femoral condylar plates, L-shaped plates	All the operations was associated whit a tibial tubercle osteotomy and realignment
Zarrouck (2019)	-	+	±	Monoplanar	Blade plate bent to 95°	/

SCFO: single-cut distal femoral osteotomy.

et al.[16] reported that 80% of the treated patients have no further episode of instability.

Discussion

This study shows that distal femoral osteotomy can be used as a reliable tool in addressing patellofemoral instability in the setting of genu valgum, as it can be demonstrated by an improvement in clinical outcome scores as well as in patellar tracking and in patellofemoral symptoms (Table 3). Also, a reduction in recurrence of dislocation and in pain scores was noted in most of the studies. While historically distal femur varus-producing osteotomy (DFVO) was intended essentially to treat early-stage lateral compartment osteoarthritis, better knowledge of patellofemoral kinematics in recent years led to the expansion of the indications for DFVO and to the extension of its use for the treatment of patellar instability under the assumption that a reduction in the Q-angle could reduce the lateral translational vector applied to the patella. However, the literature on the subject remains scarce and consists mostly of small case series. Thus, with this study, we aimed to recollect the evidence from these studies in order to review and evaluate the clinical implications of DFVO for the patellofemoral joint. With the present review, we could demonstrate that DFVO allows to obtain a reliable correction of femoral valgus which in turn improved patellofemoral tracking and stability. Clinically, this translated into improved functional scores (Kujala score and KOOS), diminished pain (VAS) and reduction of instability (mSI and CDI). Remarkably, an improvement was observed for both medial closing-wedge and lateral opening-wedge osteotomies. As a sidenote, as femoral opening-wedge osteotomy is known to normalize the patellar height while correcting the genu valgum of the patient,[24] it should be observed that patients with patella alta, which is a known risk factor for patellofemoral instability, would most likely benefit from an opening-wedge osteotomy. Similarly, closing-wedge osteotomy would be most indicated in patients with a low to normal patellar height in order to prevent the inadvertent occurrence of patella baja that could occur with an opening osteotomy. Among the 16 included studies, an average mechanical axis correction of 11.8° was noted, with 7 studies reporting undercorrection (range from 4° to 0.2°) and 3 studies reporting overcorrection (range from −0.6 to −3). Interestingly, the clinical and radiological outcomes did not differ when overcorrection was performed. Moreover, in one study the Merchant congruence angle was adequately restored and patella was medialized with a significant improvement of short-term functional results even with co-existing patellofemoral osteoarthritis. In another study, centralization on the trochlea was achieved in all patients.[24] In the study by Elattar et al.[21] all patients showed an improvement in patellar tracking. In the studies by Frings et al.[4,23] no recurrence of dislocation was observed after femoral osteotomy.

Figure 1. Describes how to measure the hip–knee–ankle (HKA) angle. Is the angle formed by two axes (white lines). The first axis runs from the center of the femoral head to the middle of the femoral notch, and the second axis from the middle of the tibial notch to the middle of the talar head of the tibia.

Figure 2. The modified Insall–Salvati ratio (mSI).

It is also relevant to note that while the patient population of the analyzed studies was highly heterogenous, with varying degrees of preoperative deformity and patellofemoral instability, DFVO seemed to be effective regardless of preoperative patient status. Even if the clinical and radiological results of the procedure looks promising, it should be noted that other additional procedures were concomitantly performed in several studied, including medial reefing or lateral release. This review, while being one of the only reviews performed on this subject, has some limitations: first, preoperative patient characteristics are extremely variable, making the drawing of generalized conclusion more hazardous despite the encouraging results hereby displayed. Second, in many of the considered studied DFVO was associated with other procedures including medial reefing or lateral release, making it difficult to adequately analyze the relative contributions of each of these procedures to the final clinical outcome. Third, as the use of DFVO to address patellofemoral instability is not widespread, the actual sample size analyzed is relatively small. Also, as most of the studies considered are probably lacking adequate power, and the level of evidence of the current review is thus probably limited.

Conclusions

According to the encouraging results showing a reduction in patellar redislocation rate and an improvement in

Table 3. The main results and conclusions of the included studies.

Abdi (2017)	Prospective study	IKDC from 65 to 71	24 months	The average mechanical tibiofemoral angle improved from 16° (10–23) to 1° (−2 to + 2). IKDC subjective score slightly improved from preoperative (65) to 2-year follow up (71). Centralization of the trochlea was achieved in all patients	SCFO can be a reasonable alternative for correction of the distal femur genu valgum deformity. It can centralize the patellar groove under the femoral anatomical axis (FAA) with satisfactory clinical outcomes	Centralization of the trochlea was achieved in all patients
Akaoka (2020)	Case series	BIOMECCANICA	42 months	All indices including mISI, mCDI, mBPI, lateral patellar tilt (LPT), and LPS showed no statistically significant postoperative changes	Medial closed-wedge DFO performed for valgus osteoarthritic knees did not significantly influence patellofemoral alignment either on the sagittal or axial plane. Therefore, to highlight the clinical relevance of our findings, medial closed-wedge DFO for the valgus knee does not adversely affect the patellofemoral joint	Medial closed-wedge DFO for the valgus knee does not adversely affect the patellofemoral joint
Barvanon (2019)	Prospective pilot study	Kujala score from 37.1 + − 14.3 to 74.6 ± 12.0 KOOS-patello-femoral (PF) from 20.08 ± 14.2 to 63.3 ± 17.0 KOOS from 24.2 ± 12.9 to 71.6 ± 16.4	24 months	The Kujala patellofemoral functional scores and the KOOS-PF showed considerable improvement with a differential of + 37.5 points ± 20.4 and + 42.7 points ± 19.3 ($p < 0.01$), respectively. The average Merchant's congruence angle went from 8.8° laterally to 3.6° medially, resulting in medialization of the patella, with a significant difference ($p < 0.01$). Based on the specific clinical analysis of the patellar joint, preoperative J-sign was identified in 26.7% of patients (n = 4) and was not found during postoperative examination ($p = 0.1$). Preoperative apprehension test was identified in 33.3% of patients (n = 5) against 13.3% (n = 2) after surgery ($p = 0.39$). Preoperative pain extension test was identified in 40% of patients (n = 6) against 20% during postoperative clinical analysis ($p = 0.43$).	The medial closing-wedge femoral varus osteotomy induces a significant medialization of the patella (Merchant's congruence angle) and improves short-term functional results even with co-existing patellofemoral osteoarthritis	The medial closing-wedge femoral varus osteotomy induces a significant medialization of the patella (Merchant's congruence angle) and improves short-term functional results even with co-existing patellofemoral osteoarthritis
Chang (2017)	Retrospective study	KSS from 46.7 ± 5.2 to 87 ± 4.4 ($p <$ 0.001) Kujala	20 ± 11.7 months	At a mean follow up of 20 ± 11.7 months (range 12–42 months), KSS improved significantly, from 46.7 ±	Use of single-incision CWDFO combined with medial reefing and lateral release prevents patellar	Use of single-incision CWDFO combined with medial reefing and lateral release prevents patellar

(continued)

Table 3. (continued)

		score from 44 ± 8 to 86.6 ± 6.8 ($p < 0.001$)		5.2 preoperatively to 87 ± 4.4 postoperatively ($p < 0.001$), as did the Kujala score, from 44 ± 8 preoperatively to 86.6 ± 6.8 postoperatively ($p < 0.001$). The Weight bearing line (WBL) decreased significantly, from 76 ± 7% preoperatively to 41 ± 11% postoperatively ($p < 0.001$). The femoro-tibial angle (FTA) was improved significantly, from 12.7 ± 1.7° preoperatively to 4 ± 4° postoperatively ($p < 0.001$), as was the mLDFA, from 83 ± 4° preoperatively to 91 ± 1.3° postoperatively ($p < 0.001$)	dislocation, corrects deformity, and improves clinical outcomes	dislocation, corrects deformity, and improves clinical outcomes
Elattar (2016)	Therapeutic study	SF-36 scores from 37.5 to 50.2 ($p = 0.01$), lower limb module (LLM) scores from 71.6 to 85.9 ($p = 0.021$), Oxford knee score was 35 ± 6.2 (range 23–46)	26 months (range 12–57 months)	The accuracy of deformity correction was 95%. The mechanical axis deviation (MAD) significantly improved from 25.3 mm lateral to the midline to 8 mm medial to the midline ($p < 0.01$). The LDFA significantly improved from 83.4° to 91.7° ($p < 0.01$). The patella congruence angle (PCA) significantly improved from 30.4° lateral to 5.7° lateral ($p = 0.02$). Mean SF-36 scores significantly improved from 37.5 to 50.2 ($p = 0.01$); mean LLM scores improved from 71.6 to 85.9 ($p = 0.021$), and the mean postoperative Oxford knee score was 35 ± 6.2 (range 23–46). No patients required total knee arthroplasty at the time of final follow up	Opening-wedge lateral DFO is a reliable procedure for the treatment of valgus knee malalignment with or without arthritic changes in the lateral compartment. Deformity correction is accurate, and patient outcomes reveal significant improvement after surgery	All patients had an improvement in patellar tracking
Flury (2020)	Imaging study	BIOMECCANICA	/	Mean preoperative Q-angle was 15.8 ± 3.9° (range 10–21.4°) with a mean preoperative mechanical leg axis of 6.5° ± 2.4 valgus (range 3.8–11.6° valgus). The Q-angle changed linearly 0.9 ± 0° per 1° of varization. No difference was detected between simulated three-dimensional	Distal femur varization osteotomy has a linear effect on the Q-angle with a change of 1° per 1° of varization. The difference in TT–TG distance was mainly due to an unintentional rotational component implemented during surgery	Combined distal femoral osteotomy in genu valgum seems to be a suitable treatment for patellar instability

(continued)

Table 3. (continued)

				Q-angles and effectively corrected postoperative values (n.s.). TT–TG distance changed irregularly and minimally, and with no correlation to the degree of varization		
Frings (2018)	Retrospective cohort study	VAS from 8.0 ± 1.4 to 2.3 ± 2.1 ($p \leq 0.001$), Kujala score from 40.1 ± 17.9 to 78.5 ± 16.6 ($p \leq 0.001$), Lysholm score from 36.1 ± 19.5 to 81.6 ± 11.7 ($p \leq 0.001$), Tenger score from 2.0 (1–5) to 4.0 (3–6) ($p \leq 0.001$)	16 (12–64) months	20 combined DFOs on 18 patients with a median age of 23 years (15–55 years) were performed. The preoperative mechanical leg axis was 6.5° ± 2.0° valgus, and the mean tibial tuberosity to trochlear groove (TT–TG) distance was 19.1 ± 4.8 mm. All patients reported multiple dislocations. Intraoperatively, 71% presented III–IV° cartilage lesions, located retropatellarly in 87% and correlating negatively with the postoperative Lysholm score ($r = -0.462$, $p = 0.040$). The leg axis was corrected by 7.1° ± 2.6°, and in 17 cases, the tibial tubercle was additionally medialized by 10 ± 3.1 mm. All patellae were re-stabilized with medial patellofemoral ligament reconstruction. After a median period of 16 (12–64) months, the pain level decreased from 8.0 ± 1.4 to 2.3 ± 2.1 (VAS $p \leq 0.001$) and knee function improved from 40.1 ± 17.9 to 78.5 ± 16.6 (Kujala $p \leq 0.001$), 36.1 ± 19.5 to 81.6 ± 11.7 (Lysholm $p \leq 0.001$), and 2.0 (1–5) to 4.0 (3–6) (median Tegner $p \leq 0.001$). No redislocation was observed	Combined DFO is a suitable treatment for patellar instability and maltracking due to genu valgum, as it leads to very low redislocation rates, a significant reduction of pain, and a significant increase of knee function with good-to-excellent results in the short-term follow up. However, a high prevalence of substantial cartilage lesions is observed, causing postoperative limitations of knee function	No redislocation was observed
Frings (2018)	Retrospective cohort study	VAS from 4.9 to 1.2 ($p < 0.001$), Kujala score from 47.7 to 84.4 ($p < 0.001$), Tegner score from 2.2 to 3.7 ($p = 0.001$)	27 months (range: 12–64 months)	We performed 19 torsional (+11.4 ± 2.4 degrees) DFOs with medial patellofemoral ligament (MPFL) augmentation ($n = 19$), tibial tuberosity transfer ($n = 14$, 10.9 ± 6.0 mm), varus ($n = 4$, 3.3 ± 1.0 degrees), or valgus ($n = 1$, 7.0 degrees) correction. Among	Patellofemoral maltracking and instability in torsional and axis deformities can successfully be treated by combined DFOs with excellent clinical results. The coexistence of risk factors for patellar instability requires a	No redislocation was observed

(continued)

Table 3. (continued)

				valgus deformities, the leg axis was 6.7 ± 2.3 degrees valgus and TT-TG 19.3 ± 5.0 mm. We performed 12 medially closing-wedge DFOs (7.6 ± 2.8 degrees) with MPFL augmentation ($n = 12$) and tibial tubercle transfer ($n = 9$, 11.4 ± 7.3 mm). Visual analogue pain scale improved from 6.2 to 1.5 ($p = 0.000$), Kujala score from 45.0 to 81.5 ($p = 0.000$), Lysholm score from 40.3 to 83.9 ($p = 0.000$), and Tegner score from 2.1 to 3.9 ($p = 0.000$). Preoperative cartilage damage significantly influences the postoperative functional outcome (Lysholm score) ($p = 0.026$) as well as the improvement in terms of the Kujala score ($p = 0.045$) in the overall collective. No redislocation was observed	combination of additional procedures to complement the osteotomy. Preoperative cartilage lesions significantly influence the clinical outcome	
Kolb (2018)	Retrospective study	KOOS5 from 60.0 (range 13.8 to 100.0) to 81.9 (range 49.4 to 100.0) (p = 0.001)	65 months (range 13–125 months)	The restoration of MAD and mLDFA resulted in significantly improved postoperative KOOS5 in younger and older patients (p = 0.001). Bone healing without bone grafting was reliable in all patients. The leg length was significantly increased postoperatively (p = 0.001). The Blackburne–Peel ratio was significantly reduced to more normal values postoperatively (p < 0.001)	lateral opening wedge distal femoral osteotomy (LOWDFO) without bone grafting is a reliable procedure representing a promising treatment option particularly in young patients with genu valgum. Besides correction of the MAD, a significant leg length increase and additional patella stability can be expected	Positive side effects of the procedure in cases of limb shortage or patella instability are significant leg lengthening and additional patella stability
Nha (2018)	Case series	BIOMECCANICA	30.7 months (range 25–62 months	At a mean follow up of 30.7 months (range 25–62 months), the mean mechanical femorotibial and mechanical lateral distal femoral angles changed significantly from valgus 5 (range 2–11) to varus 3 (2–11; p \ 0.001) and from 83 (range 78–86) to 89 (84–92; p \ 0.001), respectively. The mean patellar congruence angle improved from 40 lateral (range 20–53 lateral) to 4 medial (23 medial to 21 lateral; p \ 0.001), as did the lateral	closing wedge distal femoral osteotomy (CWDFO) combined with medial reefing and lateral release successfully treated recurrent patellar dislocation (RPD) with genu valgum for a minimum follow up of 2 years, with improved patellar alignment and stability	Patellar instability symptoms also improved, as validated by radiographic and other clinical outcomes // with improved patellar alignment and stability

(continued)

Table 3. (continued)

				patellofemoral angle from 26 (range 8–62) to 9 (0–15; p \ 0.001). Computed tomography scans showed that the mean distance of patellar lateral shift decreased from 13.5 (range 4–22 mm) to 2.0 mm (–4 to 5 mm; p\0.001). The mean tibial tubercle to trochlear groove distance significantly decreased from 20.4 to 13.5 mm (p\0.001), while the Caton–Deschamps ratio did not change significantly after surgery (p = 0.984). Chondral lesions of the patella and trochlear groove significantly improved or were maintained. None of the patients experienced subluxation or redislocation after surgery. Patellar instability symptoms also improved, as validated by radiographic and other clinical outcomes		
Omidi-Kashani (2009)	Retrospective study	BIOMECCANICA	16.3 months (range 8–25 months)	This study was done on 23 knees (16 patients) age 23.3 years (range 17–41 years). The mean duration of following up was 16.3 months (range 8–25 months). Based on paired T test, there were statistically significant difference between preoperative and postoperative tibiofemoral and congruence angles (p < 0.001, t = 21.3 and p < 0.001, t = 10.1, respectively). Pearson correlation between the amount of tibiofemoral and congruence angle correction was also statistically significant (p = 0.02 and r = 0.46)	Distal femoral varus osteotomy with blade plate fixation can be a reliable procedure for the treatment of valgus knee deformity. In this procedure, with more tibiofemoral angle correction, more congruence angle correction can be achieved. Therefore, along with genu valgum correction, the patella should be stabilized simultaneously	…
Swarup (2017)	Retrospective study	KOOS-PS scores from 33.9 to 18.9 (p = 0.14), VAS from 5.6 to 1.6 (p = 0.01), Kujala scores from 53.3 to 77.4 (p = 0.02)	27 months (23–41)	We studied 8 patients (10 knees) that underwent a lateral opening-wedge DFO for genu valgum and patellar instability. Mean follow-up duration was 27 months. PCA improved from 30.4° lateral preoperatively to 5.7° lateral postoperatively (p = 0.016).	There is an important relationship between mechanical alignment and patellar instability. Lateral opening-wedge DFO is an effective treatment for patellar instability in patients with genu valgum	None of the patients in our study experienced subluxation or redislocation after surgery. Patellar instability symptoms improved as validated by our radiographic outcomes as well as the KOOS and Kujala scores

(continued)

Table 3. (continued)

				Similarly, MAD improved from 33.1 mm lateral to 6.5 mm medial, and LDFA improved from 82.4° to 92.7° after surgery (p = 0.002). There were significant improvements in VAS pain and Kujala scores after surgery (p b 0.05), and a trend toward improvement in KOOS-PS (p = 0.14). The mean Oxford knee score at follow up was 36.25		
Wang (2005)	Therapeutic study	Hospital for special surgery knee score from 46 (20–63) to 88 (65–99)	99 months (61–169)	At the time of the most recent follow up, 25 patients (83%) had a satisfactory result and 2 had a fair result according to the Hospital for special surgery rating system. The remaining 3 patients had had a conversion to a total knee arthroplasty. With conversion to total knee arthroplasty as the end point, the cumulative 10-year survival rate for all patients was 87% (95% confidence interval, 69% to 100%). Improvement in patellar tracking, which persisted at the time of the latest follow up, was observed in 7 of the 8 knees with associated severe patellofemoral arthritis	Distal femoral varus osteotomy with blade plate fixation can be a reliable procedure for the treatment of lateral compartment osteoarthritis of the knee associated with valgus deformity. The result of the osteotomy does not appear to be affected by the presence of severe patellofemoral arthritis	Improvement in patellar tracking, which persisted at the time of the latest follow up, was observed in 7 of the 8 knees with associated severe patellofemoral arthritis// The result of the osteotomy does not appear to be affected by the presence of severe patellofemoral arthritis
Wilson (2018)	Retrospective study	Postoperative Kujala score 83.6 (range 49–99), postoperative Tegner activity score 5.5 (range 3–7)	4.25 years (3.2–6.0)	10 of the 11 patients (average age, 16 years; range 14–18 years; 4 male individuals: 7 female individuals) with an average follow up of 4.25 years (range 3.2–6.0 years) met inclusion criteria. The average BMI of all patients was 31.3 (range 19.7–46.8) with 91% considered overweight (BMI >25) and 55% obese (BMI >30). The average preoperative lateral distal femoral angle was 75.4° with an average correction of 10.4°(range 7–12°) (p < 0.001). Mean patellar height ratios were reduced; with CDI significantly reduced to 1.08 (range 0.86–1.30) (p < 0.005). The	A distal femoral varus-producing osteotomy may change radiographic parameters associated with patellar instability and improve clinical outcomes by reducing symptomatic patellofemoral instability in this patient population	8 (80%) having no further episodes of instability

(continued)

Table 3. (continued)

				average postoperative Kujala score was 83.6 (range 49–99) with 7 subjects (70%) reporting good-to-excellent function (Kujala > 80) and 8 (80%) having no further episodes of instability. The mean postoperative Tegner activity score was 5.5 (range 3–7)		
Yoshvin (2015)	Case series	Kujala score from 29.2 to 67.2	4.3 years	5 knees with congenital patellar dislocation were treated. The mean age of the patients was 29.6 years, and mean follow-up time was 4.3 years. Mean preoperative range of motion was 65, and it increased to a mean of 105.5 after surgical treatment. The mean preoperative Kujala score was 29.2 and increased to 67.2 after surgical treatment	Congenital patellar dislocations that are allowed to proceed to adulthood are difficult to treat, and surgical treatment depends on the degree of deformity of the patella and of the knee joint. This study shows that surgical treatment is able to correct the deformity and provide better knee function	There was no redislocation of the patella or failure of the internal fixation reported
Zarrouk (2019)	Retrospective study	International Knee Society (IKS) score from 49.28 (range 14–70) to 74.23 (range 41–92), mean preoperative functional score from 50.68 (range 30–80) to 72.85 (range 40–90) ($p < 0.001$)	54 months (range 36–132 months)	18 knees had good or excellent results (80%), 2 had fair results (9.5%), and 2 poor results (9.5%). One female patient underwent total knee replacement revision at 8 years and 3 others are awaiting total knee replacement. The mean preoperative IKS score increased from 49.28 (range 14–70) to 74.23 (range 41–92) at the last follow up. The mean preoperative functional score increased from 50.68 (range 30–80) to 72.85 (range 40–90) at the last follow up ($p = 0.001$). The 8-year survival rate was 91% (confidence interval, 69%–100%). We noted improvement in patellofemoral syndrome and recentering of the patella in 7 cases out of 9 with severe patellofemoral osteoarthrosis	Distal femoral varus osteotomy, with lateral opening wedge and fixation can be a good alternative to the treatment of lateral tibiofemoral osteoarthritis associated with a valgus knee originating in the femur. The association of patellofemoral osteoarthritis does not affect the functional results	Patella recentering was observed in 7 patients with an increase in the preoperative Insall–Salvati index from 1.07 to 1.15 at the last follow up. Patella recentering was observed in the cases in which the HKA angle showed a normal axis

BMI: body mass index; HKA: hip–knee–ankle; IKDC: International Knee Documentation Committee; KOOS: Knee injury and Osteoarthritis Outcome Score; KSS: Knee Society score; mBPI: Blackburne–Peel index; mCDI: modified Caton–Deschamps index; mLDFA: modified lateral distal femoral angle; MPFL: medial patellofemoral ligament; SCFO: single-cut distal femoral osteotomy; SF-36: Short Form-36 Health Survey; VAS: visual analog scale.

postoperative outcome scores, DFVO should be considered as a promising alternative to more classical procedures in the treatment of patellofemoral instability in the setting of genu valgum, and should be taken into account as one of the surgical options to address the issue of altered patellofemoral kinematics.

In the next few years, more studies should investigate the clinical and radiological outcomes distal femoral varus osteotomy with a longer follow up in order to better understand the long-term consequences of this surgery.

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