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Supracondylar femur osteotomies around the knee

Patient selection, planning, operative techniques, stability of fixation, and bone healing

Aetiopathology, indication and patient selection

A valgus leg alignment can be present congenitally or occur after lateral menisectomy, growth plate disturbances and/or post traumatically [21]. The valgus alignment itself is a risk factor for the development of lateral compartment osteoarthritis (OA) and its progression [1–3]. Lateral compartment OA is most often located posterolaterally in the knee whereas medial compartment osteoarthritis is located anteromedially [22, 23]. Anatomically the lateral tibia plateau is convex, instead of concave medially; congruency of the lateral compartment is to a much larger extent maintained by the shape of the lateral meniscus, and loss of the integrity of the lateral meniscus decreases this congruency [24]. The biomechanics of a valgus malalignment therefore might be entirely different compared to a varus malalignment [12].

Various authors have looked at the differences between lateral and medial OA. Recent research on cartilage forces and associations between variations in anatomy around the hip and leg alignment might better explain why cartilage in lateral OA deteriorates more rapidly in specific patients (◘ Table 1) [12, 22, 25–34].

The main indication for supracondylar distal femur varus osteotomy (SCO) is the correction of frontal plane valgus malalignment in lateral unicompartmental OA of the knee [1, 9–16]. A second indication is the correction of load imbalance in ligamentous instability due to chronic medial collateral ligament insufficiency to reduce the valgus thrust and to unload any ligament reconstruction [35]. A third indication is the correction of lateral patellofemoral maltracking due to the valgus leg alignment and associated abnormal trochlear orientation, to reduce the lateral displacement forces acting on the patella [36]. The second and third indications are beyond the scope of the current article, as are the possible treatment alternatives to SCO (lateral unicompartmental and total knee replacement).

Initial assessment is done using weight-bearing antero-posterior (AP) and lateral radiographs and axial views of the patellofemoral joint, as well as whole leg standing radiographs and postero-anterior (PA) weight-bearing radiographs in 45° of knee flexion [13, 21, 37–39]. The latter is used to visualise the degenerative changes in the posterior part of the lateral tibia plateau (◘ Fig. 1). Optional varus stress views may be used to show a sufficient lateral collateral ligament and adequate joint space in the medial compartment [40].

The ISAKOS guidelines on HTO in the management of knee OA can also be applied to SCO (◘ Table 2) [17]. In addition to these guidelines, it is the current authors' opinion that patients <40 years of age can also benefit from realignment, alone, or combined with a secondary cartilage procedure such as microfracture. Furthermore patients with medial compartment cartilage changes up to Outerbridge [41] grade 3 and patients with an intact remnant of the medial meniscus after partial menisectomy may be suitable candidates, provided that the leg is not overcorrected into varus. In addition to frontal plane corrections >15°, corrections up to 15° in the sagittal plane can be performed using current fixation techniques.

Correction of the deformity

In knee joints with distal femoral deformities and valgus joint line obliquity a femoral correction not only corrects the leg alignment but also normalises the knee joint line obliquity.

In many patients however the valgus malalignment may be found to be caused by a tibial or a combined tibial and femoral deformity [42]. The principles of deformity correction as formulated by Paley [43] dictate that in these cases either a tibial correction or a double level osteotomy should be performed with a resultant normal knee joint line orientation. Planning of correction using present and desired weight bearing lines provides for the angle of correction as well as the length of the wedge base on the cortex (◘ Fig. 2).

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Table 1 Causes of rapid lateral compartment osteoarthritis (OA) progression

Author	Study	Conclusion
Cartilage forces		
Pena et al. [30]	Difference in effect on cartilage of lateral vs. medial menisectomy using finite element analysis	Percentage increase in cartilage stress in lateral compartment higher after lateral then medial menisectomy
Yang et al. [31]	Combined effect of tibiofemoral knee angle and menisectomy on cartilage contact stress	Greater percentage increase of cartilage contact stress after lateral menisectomy compared to medial menisectomy with pre-existing abnormal tibiofemoral angle
Bretin et al. [59]	Influence of femoral fracture malrotation malunion on knee joint cartilage forces	Internal rotation malunions are associated with lateral mechanical axis deviation and lateral shift of cartilage forces
Anatomy and leg alignment		
Allen et al. [29]	Follow-up of late changes after menisectomy in a series of 210 patients	Increased knee OA after menisectomy in patients with pre-existent abnormal (valgus) tibiofemoral alignment and lateral menisectomy compared to medial
Weidow et al. [32]	Motion and moments in hip and knee in medial and lateral knee OA compared to control group	Association between lateral knee OA and biomechanics of the hip joint, but unknown if reason for development of lateral OA or caused by its presence
Weidow et al. [33]	Relationship between lateral knee OA and anatomical differences in the hip region	Association between lateral knee OA and wider pelvis, shorter neck, shorter head–shaft distance, shorter lever arm of the hip in lateral OA compared to medial OA
Lindgren and Seireg [25]	The influence of mediolateral deformity, tibial torsion, and foot position on femorotibial load in a computer model	External torsion and valgus deformity decreased the load in the medial compartment; with center of support on the lateral foot line, lateral compartment loaded more

Table 2 ISAKOS guidelines [17] for selection of patients suitable for SCO

Ideal candidate	Possible candidate	No good candidate
Isolated lateral joint line pain	Flexion contracture <25°	Flexion contracture >25°
Age 40–60 years	Age <40, 60–70 years	Bicompartmental disease
BMI <30	Moderate, symptomatic PF OA	Previous menisectomy in compartment to be loaded by SCO
Nonsmoker	Instability of ACL/PCL/PLC	Prior knee infection
High demand activity but no running/jumping	Wants to participate in all sports	Rheumatoid arthritis
Alignment <15° valgus		Obesity
Deformity in distal femur		Possible noncompliance
Full range of motion		Heavy smoker
<10° extension loss, >90° flexion		Soft, atrophic appearing bone on X-ray
Normal medial and PF compartments		Severe femoral bone loss
Normal ligament balance		
OA classification IKDC (A), B, C, D		
No notch osteophytes		

BMI body mass index, *PF* patella femoral, *IKDC* International Knee Documentation Committee osteoarthritis classification, *ACL* anterior cruciate ligament, *PCL* posterior cruciate ligament, *PLC* posterolateral corner, *OA* osteoarthritis, *SCO* supracondylar femur osteotomy

While a varus SCO is biomechanically efficient in the extended knee, it should be noted that in flexion the osteotomy has no effect [44]. In 90° of flexion the contact point of the loaded posterior condyles on the tibia remains unchanged by the SCO. Patients therefore should be warned that while excellent symptoms relief may be expected in extension and during gait, symptoms are likely to persist during activities that load the knee in high flexion.

Results

Well-designed studies, let alone RCTs, comparing the various available surgical options and factors that determine the outcome in SCO are not available. The largest series on SCO we are aware of are by Teitge [12] and by Freiling et al. [13], they reported on 46 and 60 patients respectively. Reported results vary from relatively poor to good at mid- to long-term follow-up; from 57 % satisfactory results at the 6.5-year follow-up, to 83 % at 99 months, and 92 % good results at the 4-year follow-up [7, 8, 10, 11]. The endpoint of survival is usually conversion to a TKA; survival up to 87 % at 99 months has been reported [7]. Finkelstein et al. [15] reported that 13 of 20 osteotomies were still successful at an average follow-up of 133 months; the probability of survival at 10 years in their series was 64 %.

There is no consensus in varus SCO on the optimal amount of correction. A correction of the anatomical femorotibial axis to 6–10° [7, 9, 10, 15, 45, 46] or mechanical femorotibial axis between 0° and 3° have all been recommended [8, 12, 13, 37, 47]. Shoji and Insall [48] identified the remaining obliquity of the knee joint line after valgus correcting osteotomies as a major prognostic factor. In a series of patients with valgus deformities and lateral compartment OA, they performed an HTO and found that if the joint line obliquity produced after the tibial correc-

Abstract · Zusammenfassung

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Supracondylar femur osteotomies around the knee. Patient selection, planning, operative techniques, stability of fixation, and bone healing

Abstract

Background. Similar to the re-appreciation of high tibial osteotomy (HTO), supracondylar distal femur varus osteotomy (SCO) for lateral compartment osteoarthritis (OA) of the knee has gained renewed interest as new knowledge has become available on the influence of malalignment on the development, progression and symptoms of OA. Furthermore, the less than optimal results of knee replacements (TKR) in younger patients have also led to renewed interest in joint-preserving treatment options.

Purpose. Varus SCO has not had the same success or widespread use as valgus HTO. The goal in SCO is similar to HTO, to shift the load from the diseased to the healthy compartment, in order to reduce pain, improve function and delay placement of a TKR. Valgus OA however occurs much less frequently than varus OA and varus SCO is considered a technically more demanding procedure. In the past the surgical techniques for SCO were mainly dependent on difficult-to-use implants making the procedure more complex. Complication rates related to the failure of fixation up to 16% have been reported.

Disussion. The new biplane osteotomy technique fixated with a locking compression plate is very stable; bone healing potential is optimal using this technique and takes 6–8 weeks. Full weight bearing before full bone healing is possible without loss of correction.

Conclusion. In this article, patient selection, planning, surgical techniques, stability of fixation, and bone healing are discussed. Varus supracondylar osteotomy is a viable treatment option for a well-defined patient group suffering from valgus malalignment and lateral compartment osteoarthritis, and in addition may be considered in ligamentous imbalance and lateral patellofemoral maltracking.

Keywords

Femur · Valgus · Osteotomy · High tibial osteoarthritis · Lateral arthritis

Suprakondyläre Femurosteotomien in Kniegelenknähe. Patientenauswahl, Planung, Operationstechniken, Fixationsstabilität und Knochenheilung

Zusammenfassung

Hintergrund. In gleichem Maße wie der Stellenwert der hohen tibialen Osteotomie (HTO) gestiegen ist, hat die suprakondyläre varisierende distale Femurosteotomie (DFO) bei der Behandlung der lateralen Osteoarthrose (OA) des Kniegelenks an Bedeutung gewonnen. Zum einen zeigen neuere Studien den klaren Zusammenhang zwischen einer Fehlstellung und der Arthroseentwicklung. Zum anderen führen die nicht zufrieden stellenden Ergebnisse nach der Implantation von Kniegelenkprothesen bei jüngeren Patienten zu einem verstärkten Interesse an gelenkerhaltenden Therapieverfahren.

Zielstellung. Die Zielstellung bei der DFO ist vergleichbar mit der HTO und besteht in der Verlagerung der Belastung vom erkrankten zum gesunden Kompartiment, um eine Schmerzlinderung und Funktionsverbesserung zu bewirken. Ein weiteres Ziel ist die zeitliche Verzögerung des Einsatzes einer Kniegelenk-Endoprothese.

Diskussion. Die varisierende DFO hat nicht denselben Stellenwert und Verbreitungsgrad wie die valgisierende HTO, da die Valgusgonarthrose seltener als eine Varusgonarthrose auftritt. Die varisierende DFO gilt im Vergleich zur HTO als technisch anspruchsvolleres Verfahren.

Schlussfolgerung. In diesem Artikel werden Patientenselektionierung, Planung, Operationstechniken, Fixationsstabilität und Knochenheilung bei suprakondylären Femurosteotomien diskutiert. Bei den bisherigen DFO-Techniken wurden mehrheitlich schwierig und kompliziert einzubringende Implantate verwendet, was das Verfahren aufwändiger gestaltete. Häufiges Implantatversagen älterer Osteotomieplatten führte zu Komplikationsraten von bis zu 16% berichtet.

Schlüsselwörter

Femur · Valgus · Osteotomie · Hohe tibiale Osteoarthrose · Laterale Arthroseentwicklung

tion exceeded 15°, especially in combination with over- or undercorrection of the frontal malalignment, rapid further degeneration ensued. Several clinical studies on double osteotomies to prevent pathological joint line obliquity have since confirmed these early observations by Shoji and Insall [42, 49, 50]. Miniaci et al. [51] reported that poor results were associated with longer time to follow-up and failure to correct the tibia–femoral angle to 0°. Similarly Mathews et al. [11] reported that good results were associated with adequate correction of the valgus deformity, to <2° from 0. McDermott et al. [10] and Cameron et al. [8] on the other hand found no correlation between alignment and outcome. All these authors aimed for correction of the anatomical axis of the femur to 0°.

Teitge [12] noted that with correct alignment deterioration was slow and that those with a less than good result were poor from the start; in those the indication to perform an osteotomy might not have been correct. Terry et al. [46] reporting on a series of 14 patients showed that using a lateral open wedge technique and a DCS for fixation at 45 months 71% of patients had a good or excellent result. The aimed correction was to a mechanical axis of 0°, alignment at final follow-up was 1.5° varus, the average shift of the mechanical axis was from a point 90% lateral from the medial side of the tibia plateau to 44%. A poor outcome was associated with a body weight of more than 1.3 times the ideal weight and with an increasing number of previous operations. Again no correlation between outcome and final alignment was found.

Table 3 Comparison of different osteotomy and fixation techniques with respect to surgical technique, bone healing and fixation stability

Osteotomy	Advantage	Disadvantage
Medial closing-wedge SCO		
Fixation technique		
Medial closing wedge SP SCO	Good bone healing potential	Supratrochlear area disrupted
	Oblique saw cuts increase stability	
Medial angled blade plate	Plate closer to WBL, lower stress/strain	Prone to hinge fracture by blade insertion
	High construct stability [19]	Blade location dictates reduction/correction
		Difficult
Dynamic condylar side plate (applied laterally)		Plate further from WBL, higher stress/strain
		Screw location dictates reduction/correction
		Prone to hinge fractures with dislocation
LCP based fixation	Ease of plate application	
	High construct stability [19, 20]	
Medial Closing wedge BP SCO	In metaphyseal bone area with highest bone healing potential	Extra saw cut
	Highest axial stability [19]	
	Smallest wedge volume [53]	
Osteotomy	Advantage	Disadvantage
Lateral opening-wedge SCO		
Fixation technique		
Lateral open wedge SP SCO	Single cut	Supra-trochlear area disrupted
	Easier approach to femur	Weak medial hinge point [12, 19]
	Easily adjustable correction	Plate location complaints [13, 57]
		Very unstable if hinge point fractures [12]
		Slowest bone healing
		Role of grafts unclear
Blade plate/DCS + screw fixation		Prone to hinge fracture by blade insertion
		Plate/screw dictates reduction/correction [12]
		Difficult
Spacer plate	Spacer supports correction [24, 39]	Low construct stability [19]
	Ease of plate application	
LCP based fixation	Ease of plate application	Low construct stability [19]

BP biplane, *SP* single plane, *DCS* dynamic condylar side plate, *LCP* locking compression plate, *SCO* supra condylar femur osteotomy, *WBL* weight bearing line

Regarding overcorrection into varus after SCO, Sharma et al. [1] in a study on the role of knee alignment in OA disease progression and functional decline found a four-fold increase in the odds of disease progression if a varus alignment was present, and a malalignment greater than >5° was associated with a significantly greater functional deterioration over the period of follow-up. The current authors correct the mechanical axis to a line passing the knee joint just medial to the deepest point of the trochlea. In severe lateral OA, in the presence of a normal medial compartment, a line slightly medial to that, i.e. just medial of the medial eminence of the tibia plateau, is used.

Osteotomy techniques and methods of fixation

In SCO, medial closing-wedge and lateral opening-wedge techniques can be used [12, 24, 37, 38, 46, 47, 51]. For fixation an angled blade plate, a Dynamic Condylar Screw and side plate (DCS), a malleable implant, staples, a plaster cast only, and an external fixator have all been used with various amounts of success with loss of correction, implant failure and delayed bone healing being the main complications reported [11, 16, 21, 46]. The medial closing-wedge technique, with saw cuts either parallel to the joint line or oblique down sloping from the medial cortex to the lateral cortex hinge point, fixed with an angled blade plate, has had the most widespread use [7–10, 12, 15, 45, 51, 52]. More recently angle stable implants, based on the LCP concept, specifically designed for the fixation of SCO have become available and a new so-called biplane SCO technique has been developed [13, 37, 38, 47].

The various osteotomy techniques and fixation methods all have their advantages and disadvantages (Table 3). An important limitation of the single plane medial closing-wedge technique is the position of the osteotomy relative to the trochlea and the soft-tissues gliding surface on the anterior side of the femur [20, 37]. While in the standard single plane technique the patellofemoral (PF) joint is avoided by proximal positioning of the saw cuts, the osteotomy does disrupt the soft-tissue gliding mechanism causing a haematoma with subsequent pain and swelling

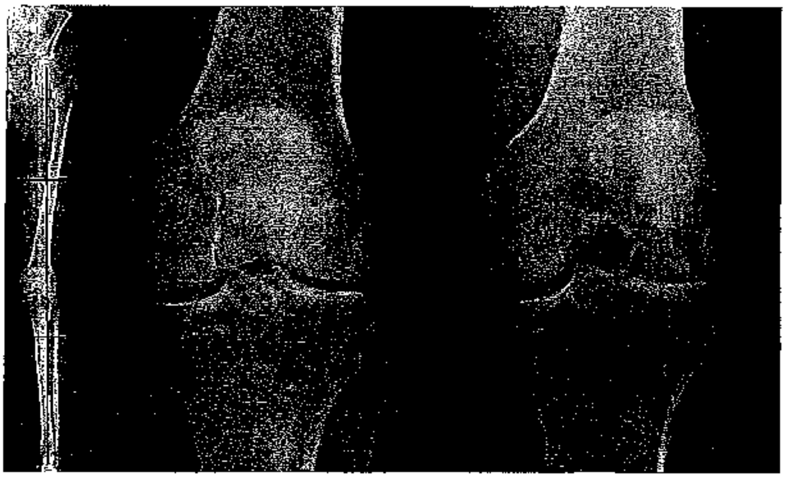

Fig. 1 ◂ Typical lateral compartment osteoarthritic left knee. Valgus leg alignment on full leg weight bearing radiograph with weight bearing line (in *red*) passing through the lateral compartment (*left*), weight bearing antero-posterior (*AP*) knee radiograph in extension shows small lateral joint space narrowing (*middle*), weight bearing postero-anterior (*PA*) knee radiograph in 45° flexion (Rosenberg view) shows severe lateral joint space narrowing (*right*). (With permission from [60], Fig. 1, page 127)

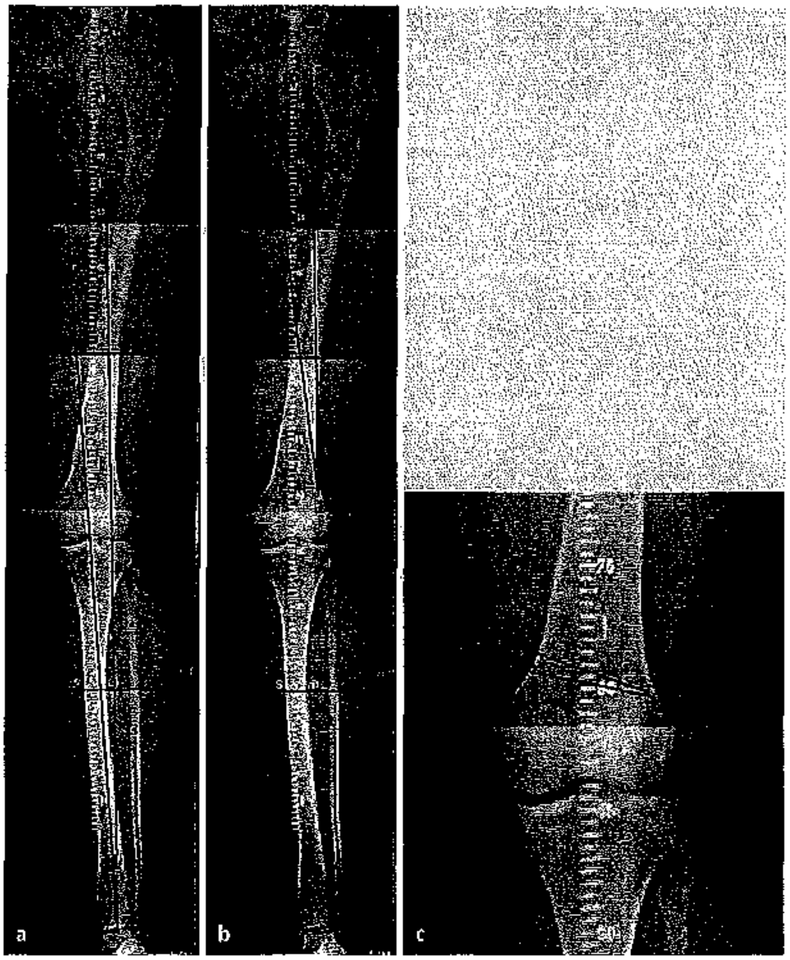

Fig. 2 ◂ Planning of a medial closing wedge supracondylar osteotomy. **a** The present mechanical axis is drawn from *A*, the center of the femoral head, to *B*, the center of the ankle joint. Line *B*–*C* is of equal length as line *A*–*B* and passes the knee just medial of the medial eminence (*arrow*) representing the desired postoperative mechanical axis. **b** The hinge point of the osteotomy (*D*) is marked just proximal from the upper border of the lateral condyle and 0.5–1 cm within the lateral cortex. The angle of correction (α) is defined by line *A*–*D* between the present femoral head center and the hinge point and line *C*–*D* connecting the new femoral head center position and the hinge point. **c** Correction angle α is projected at the distal femur using two oblique down sloping lines of equal length converging at the hinge point. The distance measured between those two lines at the level of the medial cortex (*arrows*) represents the osteotomy wedge base length to be removed during surgery. (With permission from [60], Fig. 2, page 128)

which slows rehabilitation. A modification was therefore developed by the current authors; the biplane medial closing-wedge technique [20]. In this technique the two saw cuts for the closing-wedge are made only in the posterior three-quarters of the femur after which an ascending saw cut is performed on the anterior surface of the femur, completing the osteotomy. By avoiding the trochlea, this technique enables a more distal positioning of the lateral hinge point in better healing metaphyseal bone. As the soft tissue gliding mechanism is not disrupted rehabilitation is faster [37]. Furthermore, the ascending

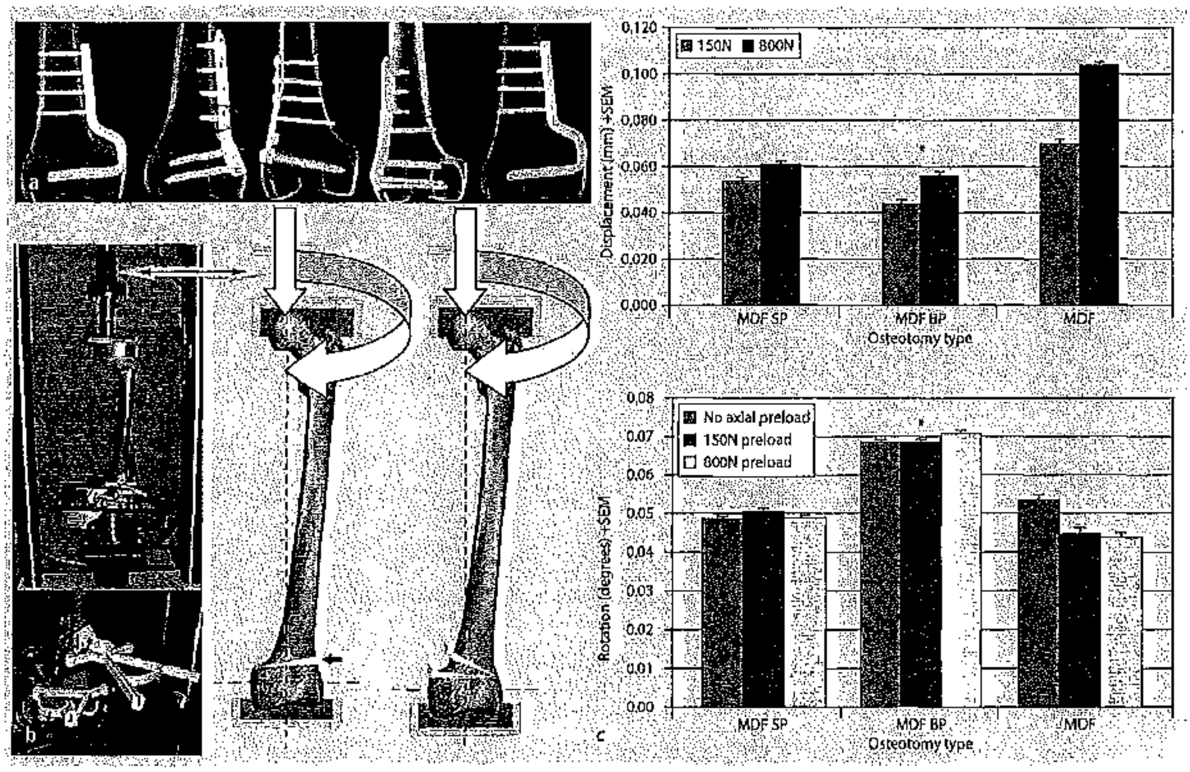

Fig. 3 ▲ **a** Overview of the five osteotomy configurations initially tested, from *left* to *right*: medial closing-wedge oblique saw cut AO blade plate, medial closing-wedge oblique saw cut LCP (Tomofix MDF), lateral opening-wedge spacer plate, lateral opening wedge LCP (Tomofix LDF), medial closing-wedge perpendicular saw cut AO blade plate [19]. *Red circle*: the uni-cortical screw initially used was replaced by a bicortical screw in the second series of tests [20]. (With permission from [60], page 132, Fig. 3A) **b** Overview of the test setup, the replica femur is loaded in an MTS with the 3D measuring system attached (*bottom left*: *1* and *2*). The direction and position of the osteotomy cuts (*bottom middle*) creating a 10° opening (*black arrow*) or a 10° closing wedge oblique (*1*) or perpendicular (*2*) osteotomy. The load applied to the femur is also shown (*middle*: *white arrows*) [19]. (With permission from [60], page 132, Fig. 3B) **c** Results of the axial loading tests (*top*) torsion loading tests (*bottom*), comparing the single plane SCO with modified proximal screw configuration (*red circle* in A, bicortical instead of unicortical) (MDF SP), the new biplane SCO (MDF BP) and the old single plane SCO (MDF). Motion is in millimeters (mm). MDF BP is statistically significantly more stable under axial loads and statistically significantly less stable under torsion loads (*)[20]. (With permission from [60], page 132, Fig. 3C, D)

saw cut increases the cortical contact area, which enhances stability and bone healing potential [20, 53].

By changing the fixation technique to a plate fixator the difficulties encountered using an angled blade plate, which caused surgeons to refrain from SCO altogether, are avoided. These difficulties include inaccurate positioning of the seating chisel and loss of stability after repositioning. This also avoids secondary displacement due to fracture of the hinge after removing the seating chisel and inserting the angled blade plate.

Lateral plate positioning on the tension side, rather than the compression side, in medial closing-wedge SCO has been advocated by some. In this scenario the plate is loaded under tension which in turn prevents lateral distraction during weight bearing [24].

The downside of lateral fixation in medial SCO however is an increase in load on the plate. It is further away from the postoperative weight bearing line (WBL), increasing the load lever arm and bending moment. This may lead to instability of fixation, delayed bone healing, implant failure and loss of reduction [12, 40].

Stahelin et al. [16] showed by measurement of bone diameters at the level of the bone cuts that, using oblique directed bone cuts of equal length forming an isosceles triangle, the bone diameter at the level of the osteotomy cuts is equal (◘ Fig. 2). After closure of the osteotomy the medial cortex can be compressed without change of correction, contrary to bone cuts aligned parallel to the joint line resulting in unequal bone diameters causing impaction and overcorrection after compression of the osteotomy. Furthermore baseline data on the initial stability of the various SCO techniques has become available [19, 20, 54]. In three biomechanical studies partial and full weight-bearing conditions after SCO corrections in replicate bones were studied. In the first study the biomechanical properties of five different SCO techniques (◘ Fig. 3) have been evaluated [19]. The angled blade plate and the Tomofix Medial Distal Femur plate (Synthes GmbH; Solothurn, Switzerland), using

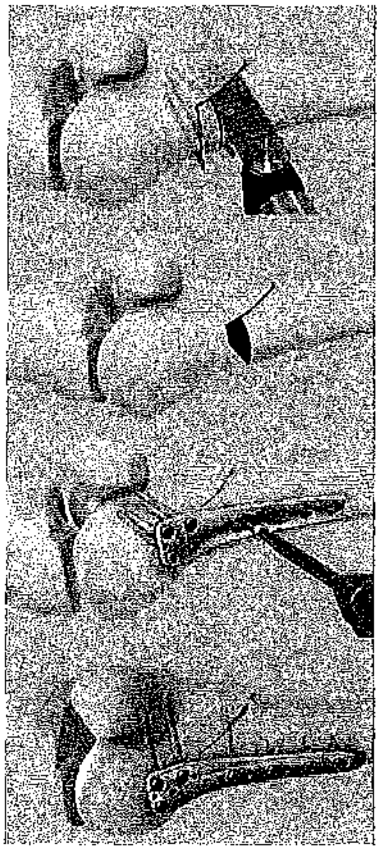

Fig. 4 ▲ *Top* to *bottom* Stepwise schematic representation of the surgical technique for a biplane closing-wedge supracondylar femur osteotomy (*SCO*) fixated by an internal fixator plate. After the transverse cuts have been made, the ascending cut of the biplane osteotomy is performed parallel to the posterior cortex. The wedge is removed and the osteotomy closed. After distal plate fixation a lag-screw is inserted to compress the osteotomy, it is replaced with a locking screw after the other proximal holes have been filled. (With permission from [60], page 132, Fig. 4A–D)

an oblique osteotomy direction provided the largest amount of initial stability. The parallel osteotomy compared to the oblique osteotomy, and the lateral open technique, whether fixated with an angle stable or a spacer plates, were less stable. In a second study the aforementioned biplane osteotomy was found to be more stable than the standard single plane SCO [20]. Subsequently, in a third study previous results on biplane SCO stability were reconfirmed using an improved, more anatomically shaped version of the angle stable (Tomofix) plate and latest 4th generation replicate bones [54].

Operative technique

The current authors preferred SCO technique is a biplane medial closing-wedge osteotomy fixated with an LCP concept based plate fixator called Tomofix Medial Distal Femur plate (Tomofix MDF, Synthes GmbH, Solothurn, Switzerland) (◘ Fig. 4) [37]. Arthroscopy, which is considered as indispensable by some, can be performed prior to the osteotomy to assess the cartilage and menisci; if needed additional procedures, including microfracturing, can be performed [55]. The whole leg should be draped free and a sterile tourniquet can be applied. The starting position of the knee is in full extension. An image intensifier fluoroscope is mandatory, with visualisation possible in two directions. The medial side of the distal femur can be either exposed by a median or anteromedial incision and a standard subvastus approach, in which the muscle needs to be stripped of the septum severing vessels and nerves at a length enabling plate fixation. Alternatively a less invasive technique can be used as described by Visser et al. [56]. A small medial incision is made at the level of the osteotomy and, instead of stripping the vastus medialis muscle (VM) off its septum, the natural interval between the distal femur and VM is used to lift the muscle ventrally.

A blunt Hohmann retractor is positioned dorsomedially at the level of the osteotomy to protect the neurovascular structures. The height and direction of the osteotomy cuts are marked with K-wires using fluoroscopy. The first K-wire for the distal saw cut is inserted at the medial cortex aimed at an approximately 20° down-sloped direction ending a few millimetres above the upper portion of the lateral femur condyle and 5–10 mm medial to the lateral cortex (◘ Fig. 2). The second K-wire is inserted proximally at the preplanned wedge base distance on the medial cortex, the ends of both K-wires meet at the hereby created hinge point of the osteotomy. Ideally, the K-wires form an isosceles triangle which can be checked by measuring the length of the K-wires outside the bone. Two additional K-wires can be positioned more posterior at the same height to guide the saw blade. Alternatively, a special saw guide can be used to precisely determine wedge size and direction. Two saw cuts are made parallel to and within the K-wires, but only in the posterior three-quarters of the femur. A third ascending saw cut is than performed to complete the osteotomy, parallel to the posterior cortex, usually at an angle of 90–95° to the other saw cuts. After wedge removal, the osteotomy is closed by applying gentle pressure; this can take a couple of minutes, to allow for plastic deformation of the bone. All bone should be removed from the gap before closure to prevent incomplete closure and lateral cortex fracture. After closure, the alignment is checked using a rigid bar over the center of the femoral head and center of the ankle joint; the new mechanical axis should run as pre-operatively planned. If needed adjustments can still be made to the osteotomy at this time.

The plate is slid proximally under the vastus medialis muscle until it is aligned with the femur shaft and then positioned anteromedially on the distal femur. After distal fixation the osteotomy is compressed manually. For additional compression an eccentrically placed screw in the dynamic part of the combination-hole directly proximal the osteotomy is used. The plate is secured proximally using three unicortical screws, and one bicortical screw just proximal from the osteotomy replacing the compression screw. In the less invasive technique the distal screws and the osteotomy-compression screw are inserted through the medial incision whereas the remaining proximal screws are inserted through a separate transmuscular stab incision positioned at the most proximal plate hole avoiding damage to major neurovascular structures [56]. The wound is closed after placement of a low suction drain under the vastus medialis.

Postoperative care and weight-bearing protocol

Postoperative cryotherapy and intermittent venous compression are recommended to reduce swelling. Starting on the first postoperative day, partial weight-bearing (15–20 kg) is allowed for the first 6 weeks, it is increased thereafter depending on

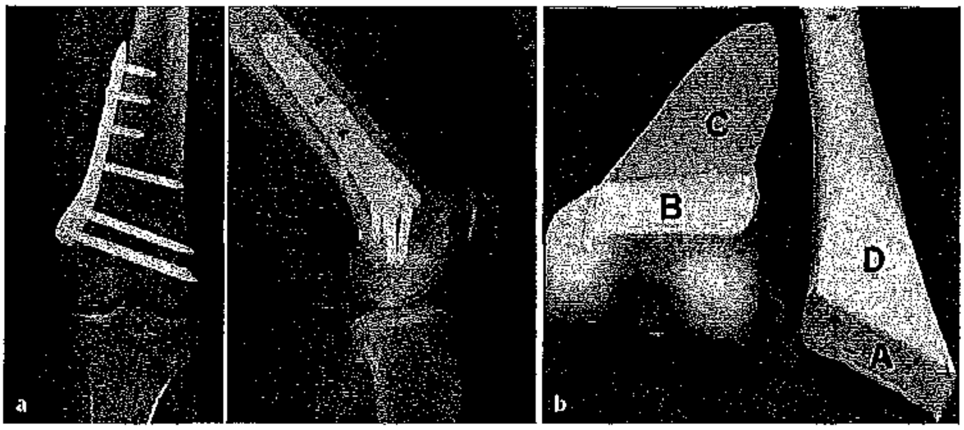

Fig. 5 ▲ Follow-up radiographs that show bone healing and bone surfaces after biplane supracondylar osteotomy in a saw bone model. **a.** Antero-posterior (*AP*) and lateral views show full consolidation at 6 weeks follow-up. (With permission from [60], page 132, Fig. 4E–F) **b.** Bone surfaces following a medial closed-wedge biplane osteotomy in a saw bone model: Transverse osteotomy plane surfaces *A* (proximal) and *B* (distal), frontal osteotomy plane surfaces *C* (ventral) and *D* (dorsal). Summation of these surfaces in square centimeter (cm^2) stratified by anatomical location show an increase in area compared to a single plane supracondylar osteotomy. (Adapted with permission from [53])

pain and signs of bone healing on follow-up radiographs.

For SCO in clinical studies reporting on the single plane technique with the TomoFix implant, no bone healing problems have been reported with a standard rehabilitation protocol consisting of 6–8 weeks of partial weight bearing [37, 47]. Clinical results seem to correlate with the biomechanical observations concerning construct fixation strength and the biplane osteotomy technique. Van Heerwaarden et al. [47] reported no loss of correction related to the implant and no failures of fixation material in 59 single plane osteotomies fixated with the Tomofix plate. Freiling et al. [37] reported on 60 medial closing wedge osteotomies half of which were biplane and found three nonunions overall, none of which were related to implant failure.

However, after introduction of the biplane technique a faster recovery of knee function was observed by the current authors as compared with the single plane patient groups, patients themselves increased the amount of weight bearing within the first 6 weeks after the osteotomy as they experienced sufficient stability to allow full weight-bearing.

Although Brinkman et al. [20] demonstrated that the biplane OT is much more stable than single plane OT under axial loads, they did find torsional stability to be slightly decreased. Therefore postoperatively physical activities, which produce high torsion loads on the femur, are probably best avoided until bone healing has been observed.

The use of braces to improve stability and protect the osteotomy has been documented by various authors. Healy et al. [9] used a brace if the fixation of the osteotomy was questionable, Wang et al. [7] and Miniaci et al. [51] both also used braces. All three authors in their series of patients used an angled blade plate for fixation and a limited weight-bearing protocol initially, varying from non-weight bearing to toe-touch for 6 weeks. Full weight bearing was allowed after 12 weeks or if clear signs of consolidation were present on follow-up radiographs.

Based on the results of the biomechanical studies [20, 53, 54] and clinical experience a clinical study has been started using early full weight-bearing (after 2 weeks) and a hinged brace preventing torsional loading until full bone healing in patients after biplane medial closing-wedge SCO fixated with the Tomofix implant [57]. For lateral opening-wedge SCO patients rehabilitation should be more careful because the osteotomy construct is less stable [14] and bone healing is slower [12, 37, 58].

Bone healing in SCO

The general principles of bone healing apply to closing-wedge osteotomies, which can be considered optimally controlled fractures treated according to standard protocols for fracture treatment, with radiographs taken at regular intervals to monitor bone healing. Bone healing in closing wedge osteotomies however may be faster than in fractures if initial stability is optimal because the hinge point remained intact. Bone healing in the distal femur then is normally complete after 6–8 weeks (◘ Fig. 5). Methods to prevent hinge point fracture are careful clearance of uneven saw cut surfaces and bone remnants after wedge removal, weakening of the lateral cortex before closure by chisels or small bur holes, and a slow paced wedge closure. Initial stability can be furthermore optimised by using oblique saw cuts and by compressing the osteotomy using either a compression device or the compression screw technique (◘ Fig. 4). Similar to fractures, bone healing in osteotomies is slowed by smoking and instability, insufficient implant fixation strength and/or hinge fracture.

Van Heerwaarden et al. [53] studied bone geometry and wedge volume after SCO, comparing lateral open and single and biplane medial closing techniques and found the biplane medial closing wedge SCO to have the best bone healing potential compared to other SCO techniques. They found that using the biplane technique a smaller wedge volume and a larger bone surface contact area are created, arguing that this would improve bone healing and stability (◘ Fig. 5).

In the lateral opening-wedge technique concerns exist regarding the stability of fixation and ability of the construct to retain the correction. Bone healing has been documented to take longer, time to full weight bearing is longer and often an iliac crest graft is needed to fill the defect [13, 19, 47, 58]. Various authors could not recommend this technique because of a large number of nonunions and iliotibial band irritation because of plate location [13, 58].

Conclusion

Varus supracondylar osteotomy is a viable treatment option for a well-defined patient group suffering from valgus malalignment and lateral compartment osteoarthritis, and in addition may be considered in ligamentous imbalance and lateral patellofemoral maltracking. The new biplane osteotomy technique fixated with an LCP is very stable, bone healing potential is optimal using this technique, and takes 6–8 weeks. Full weight bearing before full bone healing is possible without loss of correction.

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Compliance with ethical guidelines

Conflict of interest. J.-M. Brinkman, D. Freiling, P.l. Lobenhoffer, A.E. Staubli and R.J. van Heerwaarden state that there are no conflicts of interest.

The accompanying manuscript does not include studies on humans or animals.

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