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Double Level Osteotomy of the Knee for Varus Osteoarthritis

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Abstract

High tibial osteotomy (HTO) has been a well accepted surgical procedure for knees with varus knee osteoarthritis. It is an excellent option for patients who are younger and have higher functional demands. However, correction of a severe varus knee by isolated (HTO) would require a significant opening which will invariably lead to joint line obliquity (JLO) and increase the risk of complications such as hinge fractures. As such, double level osteotomy (DLO) consisting of a HTO and distal femoral osteotomy (DFO) has been purported as the preferred joint preserving procedure in patients with severe varus deformity. DLO is able to restore the mechanical alignment of the limb without causing JLO. In this narrative review, we explore the pathomechanics of varus osteoarthritis, surgical considerations for DLO planning, indications, outcomes and complications of DLO. We have also presented our preferred approach for DLO.

Pathomechanics of Varus Osteoarthritis

The knee joint includes tibiofemoral and patellofemoral articulations. The tibiofemoral articulation has a complex three dimensional range of motion with six degrees of freedom secondary to asymmetry of femoral and tibial condyle anatomy. The primary motion, however, is in the sagittal plane with flexion and extension range of movement 0-130° actively and -5-160° passively. During the gait cycle the peak forces exerted on the tibiofemoral compartment are approximately three times body weight [1]. During activity the point of loading through the knee joint, however, varies through the gait cycle. One of the original theories suggested that the knee behaves as a 'four-bar' linkage, however, this has since been refuted as too simplistic a model with the reality being that the knee and ligamentous stabilisers have a multi-plane motion including femoral rollback, slide and rotation. As a result, the tibial femoral contact point changes throughout the range of movement with greater excursion on the lateral compartment due to a concave bony anatomy and a mobile meniscus. The advantages of these mechanisms include preservation of lever arm for the quadriceps and tibial clearance in deep flexion avoiding bony impingement. The stability of the knee join throughout this range of movement relies on static and dynamic restraints however this is beyond the scope of this article, however, it is worth commenting that progressive loss of structures including cartilage and meniscus contribute to the altered biomechanics seen in osteoarthritis.

Abnormal knee biomechanics, the disease of osteoarthritis and the application of osteotomy predominantly concern the coronal plane alignment of the knee. The 'biomechanical axis' of the lower limb is defined as a line from centre femoral head to centre tibial plafond and is also referred to as the 'Mikulicz line'. In a single leg stance the biomechanical axis in a normally aligned knee will distribute forces equally between medial and lateral compartment but this changes both with activity and with abnormal biomechanical alignment. The position of the biomechanical axis relative to the knee defines genu varus and genu valgus (Figure 1). The biomechanical axis normally transects the knee at 10mm medial to the midline but in the abnormal varus knee the biomechanical axis transects the medial compartment

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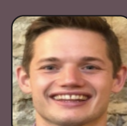
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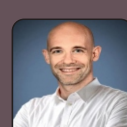
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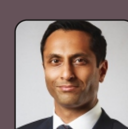
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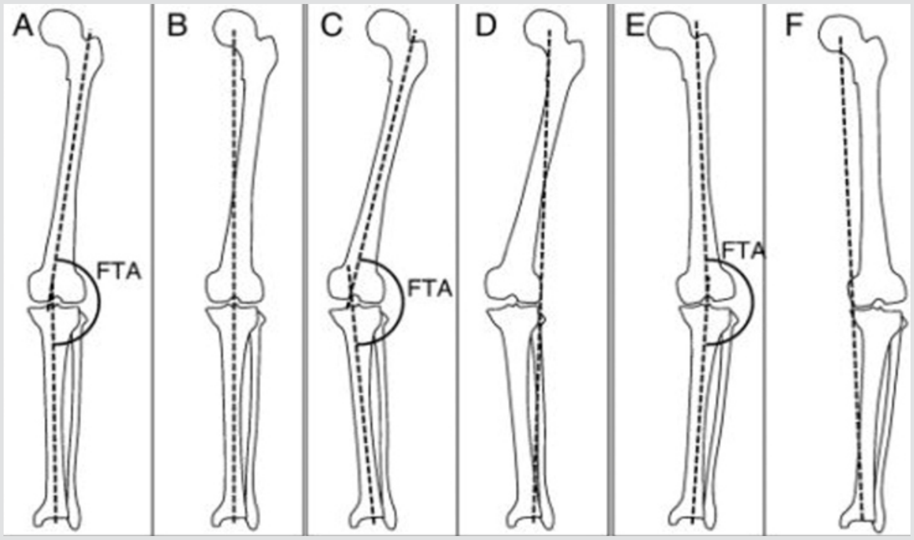

Figure 1: When the biomechanical axis passes within the mid-point of the knee joint, the mechanical alignment is deemed to be normal (A, B). When the biomechanical axis transects the knee through the lateral compartment, the mechanical alignment is deemed to be in valgus (C, D). When the biomechanical axis transects the knee through the medial compartment, the mechanical alignment is deemed to be in valgus (E, F). (Abbreviation: FTA – femorotibial alignment)

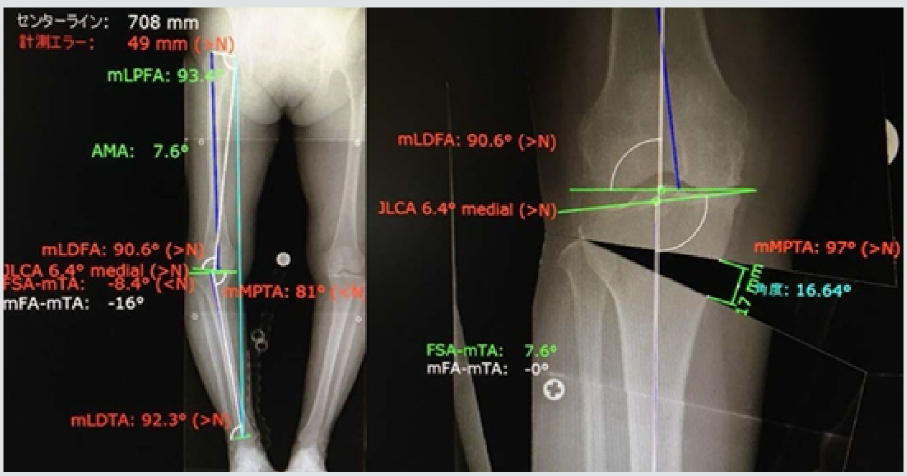

Figure 3: A digital planning template illustrating joint line obliquity following isolated high tibial osteotomy

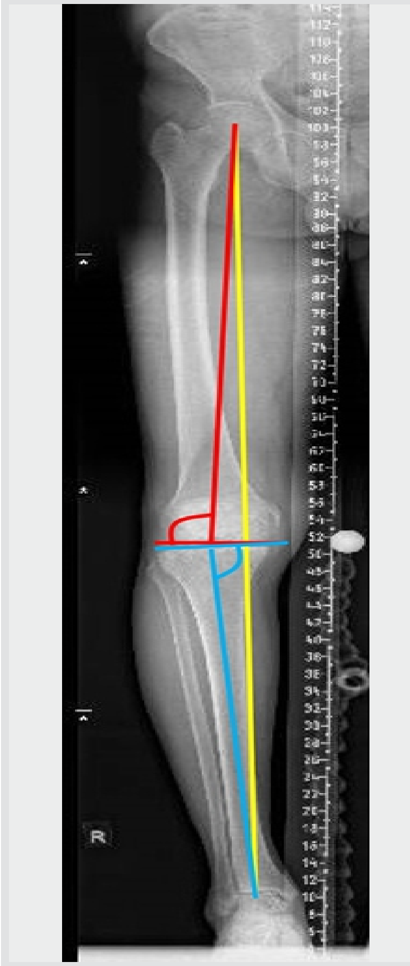

Figure 2: A calibrated long leg film showing the key lines and key angles. The Mikulicz line is represented by the yellow line. The angle subtended by the red lines is the mLDFA while the angle subtended by the blue lines is the MPTA.

increasing the medial compartment load [2]. There are two factors that contribute to this unequal load between medial and lateral compartment during gait. Firstly, the limb is in relative adduction compared to the centre of gravity of the body and secondly there is a dynamic shear force acting across the knee joint in a lateral to medial direction due to coronal plane torso swing in the stance phase of gait [3].

The effect of the biomechanical axis transecting the medial compartment is well established and the consequence is varus osteoarthritis. The nature of this condition is known to be a vicious cycle as increased peak load leads to meniscal degeneration, chondral loss and ultimately worsening genu varus.

A spectrum of treatment options exist for this condition, however, osteotomy techniques are undergoing a resurgence in popularity as a joint preserving procedure. Candidates for osteotomy are typically physiologically younger patients, BMI under 30 with relative preservation of articular cartilage, a confirmed biomechanical deformity and a desire to engage in an active lifestyle. The aim of osteotomy is to counter the progression of medial compartment osteoarthritis by balancing the adduction moment during gait. This is achieved by translating the biomechanical axis towards the midline of the knee – known as a valgising osteotomy and therefore distributing peak load away from the affected medial compartment. A well established and commonly described technique to achieve this in the 'high tibial osteotomy' (HTO) however distal femoral (DFO) and combined double level osteotomy (DLO) also have a role.

Considerations when Planning for an Osteotomy

Nomenclature for assessment and planning

Assessment of a limb for purposes of coronal plane osteotomy relies on a number of established 'normal' parameters. In the coronal plane the biomechanical axis, described previously, needs to be measured on a long leg standing antero-posterior x-ray. 'Mechanical Axis Deviation' (MAD), described by Paley et al, is the result of malalignment and is defined as the horizontal distance in the coronal pane between the normal mechanical axis of the knee (10mm from centre plateau (range 3-17mm) and the biomechanical axis [2]. The aim of osteotomy is to translate that abnormal biomechanical axis away from the affect medial

Figure 4: An additional 2mm wire is passed from the medial border of the distal femur to protect the medial hinge

Figure 5: Once the two ends of the osteotomy are in contact, a plate is applied and the hinge compressed. A cannulated headless compression screw may also be inserted through the hinge protection wire.

Figure 6: Post-operative long-leg film shows that the mechanical axis has been corrected with a normal joint line orientation. Anteroposterior and lateral views of the knee show good implant positions.

compartment. There are a number of methods described in the literature to define the correction point. Fujisawa et al recommended a point 65–70% along the tibial joint line from medial to lateral [4]. Marti et al recommended correction to the mid-point of the width of the tibial plateau (50%) if there had been no loss of articular cartilage thickness, 55% if one-third cartilage loss in the medial compartment up to 65% if there had been complete loss of the joint space [5]. Controversy exists, however, as to the effect on the lateral compartment if over-correction occurs due to the poor congruity of the lateral compartment and the inherent susceptibility to articular contact stresses [6]. In our practice, we aim for 55% across the tibial plateau from medial to lateral as this has shown better joint geometry and lesser patellofemoral joint problems [7].

Key lines (Figure 2):

- Biomechanical axis ('Mikulicz line'): centre of femoral head to centre tibial plafond
- Mechanical axis of the femur: centre of femoral head to centre distal femur
- Mechanical axis of the tibia: centre of proximal tibia to centre of tibial plafond
- Tibiofemoral joint line: lines parallel to articular margins of femoral and tibial condyles respectively

Key angles (Figure 2):

- Mechanical lateral distalfemoral angle (mLDFA): angle between the mechanical axis of the femur and the tibio-femoral joint line (normal = 87°, range 88-95°)
- Medial Proximal Tibial Angle (MPTA): angle between the anatomical/mechanical axis of the tibia and the tibiofemoral joint line (normal = 87°, range 85-90°)

Method of planning

Miniaci et al described a method of coronal plane correction which has since been modified for application to medial opening wedge HTO [8]. We have described this modified technique in detail in a previous publication [9]. Selection of a site for osteotomy needs to take into account the local soft tissue, the ligament integrity, the bony architecture and opportunity for healing [3]. It is important to note that selection of this site is not benign. The ideal site for an osteotomy is close to the centre-of-rotation and angulation (CORA). If an osteotomy is distant from the CORA, additional unplanned translation and angulation may occur. In the majority of cases however it is accepted that benefits of placing the osteotomy in the metaphyseal

Table 1: Studies that have reported outcomes following DLO

Authors	Year	Number of patients (knees)	Mean Age in years (range)	Male:female ratio	Clinical outcome scores (mean ± SD or range)		Mechanical axis (mean ± SD)		Number of complications
					Pre-op	Post-op	Pre-op (varus)	Post-op (Valgus)	
Babis *et al* (15)	2002	24 (29)	50 (20–65)	11:01	Knee Society Score KS: 34 (6–60) FS: 64 (35–100)	KS: 90(54–100) FS: 81 (35–100)	13.9° ± 4.0°	3.1° ± 3.4°	3 (1 collapse of femoral osteotomy, 2 patients residual varus >4 degrees)
Saragaglia *et al* (17)	2012	39 (42)	50.9 (39–64)	29:9	Lysholm-Tegner 41.2 ± 8.9	83.3 ± 7.5	12.3° ± 3.5°	1.83° ±1.80°	1 (recurrence of deformity due to collapse of femoral osteotomy)
Schröter *et al* (16)	2019	24 (28)	50 (30–66)	23:5	Lysholm-Tegner *Not available*	88 ± 13	11.0° ± 3.0°	0.0° ±2.0°	1 (fracture of medial hinge of femoral osteotomy)
Nakayama *et al* (18)	2020	20 (20)	62.5 (45–76)	5:15	KOOS 201 ± 69.4	380 ± 52	13.5° ± 3.1°	0.8° ± 2.4°	1 (popliteal artery injury)

Abbreviations: KOOS - Knee injury and Osteoarthritis Outcome Score (KOOS); KS – Knee Score; FS – Function Score region outweighs the risks [10].

Concept of joint line obliquity

HTO for varus knee osteoarthritis can provide satisfactory correction in relatively mild, tibia dominant deformity. However, one cannot assume that all the deformity in a varus knee is in the proximal tibia. In a significant number of patients with a varus malalignment, the deformity could be in the distal femur or in both the distal femur and the proximal tibia [11]. In these patients, an isolated HTO will generate a change in the tibial femoral joint line and induce 'joint line obliquity' (JLO) [12] (Figure 3). It has been shown that JLO of more than 5 degrees induced excessive shear stress in the tibial articular cartilage [13]. In these cases, a DLO may be indicated.

Indications for Double Level Osteotomy

DLO is a combined osteotomy of the distal femur and proximal tibia first described by Benjamin in 1969 for the surgical treatment of painful arthritis including rheumatoid arthritis [14]. DLO is indicated in situations where a single level osteotomy would generate an unacceptable joint line obliquity [13, 15]. Schroter et al outlined that a DLO is indicated if (i) the initial assessment showed a combined tibial and femoral deformity (mLDFA >90° and MPTA <87°) or (ii) if post-HTO templating showed an excessive tibial correction was required (MPTA >94°) [16].

Clinical Outcomes of Double Level Osteotomy

Historically, DLO was used in the treatment of patients with irretractable pain from arthritis, often in the absence of any coronal plane deformity [2, 5]. The procedure was performed via an intra-articular approach and left without internal fixation, with deformity corrected only where possible with moulding about a cylinder plaster cast. Clinical outcomes were mixed, with no study able to replicate the excellent results reported by Benjamin in the first description of DLO [14]. Due to these significant differences in indication and technique when compared to current practice, these early studies will not be considered in our review of outcomes following DLO. Despite recent interest in DLO, there is a relative paucity of literature. In the studies that have been performed thus far, heterogeneity of patients as well as outcome measures have made it difficult to make meaningful conclusions (Table 1) [5-18].

Radiological outcomes

The aim of a DLO in the varus knee is to unload the medial joint compartment whilst simultaneously normalising knee joint angles and the joint line congruence. It is generally agreed that correction to neutral or slight over-correct into valgus is desirable to achieve adequate unloading of the medial compartment [18].

Schröter et al set specific radiological goals of surgery, aiming for a correction of 0 to 2° of valgus, with the average planned MPTA and mLDFA of 91°±2° and 86°±1°, respectively [16]. In their study, the mean post-operative values were 0°±2° for the lower limb mechanical axis (MA), 89°±2°for the MPTA and 87°±2° for the mLDFA. In an earlier case series of 42 patients, Saragaglia et al set similar radiological targets [17] with the MA target met in 39 cases (92.7%) and the MPTA target in 36 cases (88.1%). The higher accuracy of intervention in this series may be have been contributed to by the use of computer navigation intra-operatively. Furthermore, the authors stressed the importance of using a radiographic protocol to allow for reproducible pre- and post-operative measurements to avoid potential inaccuracy from imaging. It has been shown that intraoperative methods used to verify the correction can be inaccurate [19].

Most recently, Nakayama et al presented a series of 20 patients undergoing DLO with excellent results [18]. Pre-operatively, varus deformity was universally present with a mean MA, mLDFA and MPTA of 13.5°, 91.2°and 82.3°, respectively. Osteotomy planning software was used, with the goals of DLO set to 0.5 to 1° of valgus, an mLDFA of 85° and an MPTMA of 90°. Correction was highly accurate, with a mean MA of 0.8° valgus, with parameters of joint line obliquity all restored to within normal limits (mean MTPMA: 90.6°, mLDFA: 85.5°). In contrast to other studies, all patients in this series underwent a minimally invasive biplanar osteotomy and fixation with a locking compression plate.

In contract to more recent studies, Babis et al set radiological targets for surgical intervention based on the medial plateau force, as calculated by osteotomy simulation software [15]. This led to a more variable and valgus target MA than seen in other studies (mean: 3.6°, range: 1.8°–5.1°). Pre-operative varus was on average 13.9° (range: 8.7°–25.3°) while the postoperative correction was on average 3.1° (range: -10.6°–4.9°). Two cases had a residual varus deformity (4.6° and 4.9°) and 10 cases were corrected beyond 4° of valgus. The pre-operative goal to maintain or restore joint obliquity to within 4° of neutral was achieved in 89% of cases, with three patients having joint inclination greater than 4° following correction.

Objective outcomes

The case series by Babis et al consisted of 29 knees in 24 patients with the longest average follow up of any of the series at 82.7 months (range: 27–137 months) [15]. The majority of these patients had a severe varus deformity with underlying arthritis, although two patients with post-traumatic varus deformity of the femur and one patient with severe genu varum but no radiographic evidence of arthritis were also included. Functional assessment was carried out using the Knee Society Score (KSS), which comprises of two sections, the knee score that rates the knee joint itself and a functional score that rates the ability of the patient to walk and climb stairs [20]. Each section has a maximum score of 100 points. A statistically significant increase in both sections was seen postoperatively ($p=0.079$). These differences were also well above the minimal clinically important difference (MCID) for the KSS following osteotomy procedures. The mean post-operative KSS achieved by these patients was also under the 'excellent' category (Table 1) [21]. However, a very slight reduction in range of motion was seen, from 118 ° pre-operatively to 115° post-operatively. Only one patient had gone on to have a total knee arthroplasty at the time of final follow up.

The clinical outcomes of 42 patients that underwent computer-assisted DLO for genu varum show similar patient demographics and promising results, although a different scoring system was used [17]. Functional assessment using the Lysholm-Tegner score showed an increase from 41.2 pre-operatively to 83.3 post-operatively, interpreted as a 'good' level of function [22, 23]. This scoring system was also used by Schröter et al in the retrospective analysis of 29 patients who underwent DLO [16]. The mean post-operative Lysholm-Tegner score was comparable at 88. However, no pre-operative Lysholm-Tegner score was reported making it difficult to assess if the MCID was achieved.

Patient-reported outcomes

High levels of patient satisfaction were reported in all four studies. In the series by Babis et al, all patients seen at follow-up reported the knee to feel better following surgery and 79% reported pain to be gone or only mild and occasional [15]. In the series by Saragaglia et al, 40 of the 42 patients were either satisfied or very satisfied with the results of surgery and excellent function was reported when assessed with the Knee injury and Osteoarthritis Outcome Score (KOOS), scoring a mean of 95 (range: 89–100) [17]. Schröter et al reported that all patients in their series stated they would undergo the same procedure again, and pointed out that four of their patients went on to have a DLO performed on the contralateral side [16]. Excellent International knee Documentation Committee (IKDC) subjective scores were also reported post-operatively, with a mean of 77 . Nakayama et al also reported statistically significant increases in the KOOS (pre-op: 201; post-op: 380) and IKDC scores (pre-op: 32; post-op: 59) , with both achieving their respective MCIDs [18].

Complications

The most common complication was collapse of the distal femoral osteotomy [15-17]. A popliteal artery injury that occurred during the femoral osteotomy was also reported [18]. This required repair by a vascular surgeons and was further complicated by peroneal nerve palsy secondary to compartment syndrome . These cases highlight that whilst the DLO is a relatively safe procedure, accurate surgical technique is paramount and there remains the risk of significant neurovascular injury While the risk is small, it should be discussed with patients prior to surgery.

Our Preferred Approach

Positioning

The patient is positioned supine on a radiolucent table. A high thigh tourniquet is optional, we prefer to have one in place and this must be positioned high enough to allow access to the distal third of the femur. The contralateral leg is lowered to allow access to the distal femur for the surgical approach and ease of access for the image intensifier. Prior to prepping and draping, an image is taken to make sure there is sufficient room to access the hip, knee, and ankle joint with the image intensifier.

Lateral closing wedge distal femoral osteotomy

An incision is centred laterally over the femur, the distal extent of the incision is in line with the superior pole of the patellar and is extended 10-12 cm proximally. Following an incision through the skin, an approach is made on to the iliotibial band. An incision is made through the iliotibial band and extended proximally and distally. In the distal extent of the incision, Kaplan's fibres may be encountered and are preserved. The vastus lateralis is then identified and the posterior margin of this is carefully dissected and protected. A blunt retractor is placed underneath the vastus lateralis and lifted over the femur to reveal the lateral aspect of the distal femur. Gentle traction is applied to identify the perforating vessels, and these are carefully ligated. A periosteal elevator is used to elevate tissue from the posterior lateral border of the femur and pass across the femur through to the medial side. This process is repeated to make sure there is no tissue attached to the posterior aspect of the femur and this is replaced with a radiolucent Hohman's retractor. This process allows adequate protection of the neurovascular structures and give enough room to place a retractor to allow safe passage of a saw when performing the osteotomy.

Two guide wires are positioned on the lateral cortex as per pre-operative planning. The distance from the lateral cortex to the hinge point for each wire should be an equal distance to create an isosceles triangle. The purpose of this is so that on closing the osteotomy, there is no residual step. Under fluoroscopic guidance, the wire is passed up to the planned hinge point which is located above the medial femoral condyle. An additional 2 mm guidewire is placed from the medial border of the femur so that it goes across the hinge point from a distal to proximal direction. This has been shown to provide biomechanical stability at the hinge point during the opening or closing of the osteotomy and is routinely performed by the authors (Figure 4).

The planned osteotomy wedge will start from the posterior aspect of the femur and terminate three quarters anteriorly. The remaining one quarter is preserved to perform the biplane aspect of the osteotomy. With a radiolucent Hohmann's in place to protect the neurovascular structures, a tip oscillating saw is used to perform the osteotomy along the direction of the guidewires. A particular focus is placed on making sure the posterior cortex is cut along the full length of the posterior femur up to the hinge point. A similar cut is performed along the second guide wire and once this is done, the guide wires are removed.

The biplane osteotomy is then performed. The angle at which this is performed is judged by the native anterior bow of the femur and is typically 110°. It is essential to exit the proximal aspect of the biplane osteotomy at the anterior femur. The saw is then sequentially passed lateral to medial until the entire length of the biplane is cut up to the hinge point.

The wedge should now be mobile, if not, an osteotome may be utilised to see if there is any residual bone that has not been cut. The saw may need to be passed once again to adequately clear any bone. The wedge is then removed and gentle axial pressure is applied to gradually close the osteotomy. At this stage, it is useful to place the saw in the osteotomy gap to make sure there is no residual bone that may prevent the two free ends of the lateral/medial cortex from coming into contact. Once the two ends are in contact, an osteotomy plate is applied and depending on the system you may use, the hinge is compressed during plate application (Figure 5).

Medial opening wedge high tibial osteotomy

The medial opening wedge HTO is performed in standard fashion to achieve the pre-planned osteotomy gap. The authors preferred approach has been described in detail in a recent publication [9]. Post-operative radiographs are used to confirm that the goals of the DLO have been achieved (Figure 6).

Pearls and Pitfalls

Pearls

- Position the contralateral limb in a slightly extended lowered position to allow access for the image intensifier and easier access to the medial border of the tibia for the medial opening wedge HTO
- Place the hinge for the lateral closing wedge DFO in an oval area just off the medial condyle of the femur where the medial gastrocnemius origin is attached
- Run the oscillating saw along the osteotomy gap while closing the DFO to clear any debris which might be inhibitive

Pitfalls

•Always perform an intra-operative check on the mechanical axis after the DFO before proceeding to the HTO as often we could have "over-cooked" the DFO

•Inadequate release of the MCL may prevent the HTO from opening

•Gradually open the osteotomy gap for the HTO as sudden or aggressive opening may cause a hinge fracture

Conclusion

A patient-specific and deformity-specific approach is necessary in joint preserving osteotomy for patients with varus osteoarthritis. In patients with severe varus, a DLO may be needed to restore the mechanical axis as well as to correct the malalignment in the distal femur as well as the proximal tibia to maintain joint line orientation. DLO has good outcomes when performed for the right indications. Pre-operative planning is imperative to ensure that the goals of surgery are achieved with minimal complications.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the Journal. The patient understands that his name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.

Conflict of Interest: NIL; **Source of Support:** NIL

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