Understanding Osteotomy: A narrative review

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Abstract

Osteotomy around the knee is an effective surgical procedure for active, physiologically young patients with symptomatic unicompartmental osteoarthritis (OA) and malalignment. It restores the correct lower limb mechanical alignment, redistributing weight-bearing from a damaged joint surface area to an undamaged one. Hence, it consistently provides relief in knee pain, improves knee function, and delay the need for TKA. Despite all these advantages its popularity was decreasing in the past but improved meniscal and cartilage restoration techniques renewed interest in knee osteotomies in young patients with knee pain and joint surface defects. Hence, in the last decade, the majority of osteotomies have been performed in combined with cartilage repair, meniscal transplantation, and ligament reconstruction. Understanding the rationale of an osteotomy and the possibility to combine it with other procedures allows us to obtain the most clinical benefit for the patient. This review article provides an overview of the basic osteotomy planning for knee axes malalignment, describing the different techniques based on the location of the deformity and the presence of associated lesions, thus presenting the main results of isolated and combined procedures, to provide useful updates to guide the surgeon in the choice of possible variants or associated gestures.

Keywords: Deformities around the knee, High tibial osteotomy, Clinical outcome.

Introduction

Osteotomy is one of the oldest surgical technique and still an important procedure for active, physiologically young patients with symptomatic unicompartmental osteoarthritis (OA) and malalignment.

The rational of an osteotomy around the knee is to restore the correct lower limb mechanical alignment, redistributing weight-bearing from a damaged joint surface area to an undamaged one.

The modern osteotomy techniques for knee deformities correction go back to the late 50s, thanks to the work of Jackson [1] followed by those of Wardle [2] and Coventry [3].

In the 80s, suboptimal results of total knee arthroplasty (TKA) in young patients (<60 years old) led osteotomy to gain increased popularity as a valid treatment for unicompartmental OA or deformities thanks to the favorable outcomes due to the articular load redistribution and new fixation devices [4]. The advantages of osteotomy in respect to TKA are the preservation of bone stock and articular proprioception, that allow high functioning levels, delaying the need for the joint replacement [5]. Nowadays, a wide number of techniques are described according to the type and location of the deformity and to the presence of associated lesions. Indeed, an osteotomy can be combined with articular procedures, such as anterior cruciate ligament (ACL) reconstruction, meniscal transplantation, cartilage procedures, and biological treatments, with the aim to restore normal knee biomechanics as much as possible. Hence, orthopedic surgeons should carefully evaluate all these aspects during pre-operative planning, considering obtainable results from isolated or combined procedures.

The purpose of this narrative review is to provide an overview of the basic osteotomy planning for knee axes malalignment, describing the different techniques based on the location of the deformity and the presence of associated lesions, thus presenting the main results of isolated and combined procedures, in order to provide useful updates to guide the surgeon in the choice of possible variants or associated gestures.

Deformity evaluation

The assessment of the knee deformity should begin with an accurate collection of patient's medical history, age, sex, body mass index (BMI), smoking habits, activity level, comorbidities should be noted and the elimination of additional risk factors that may affect the outcome

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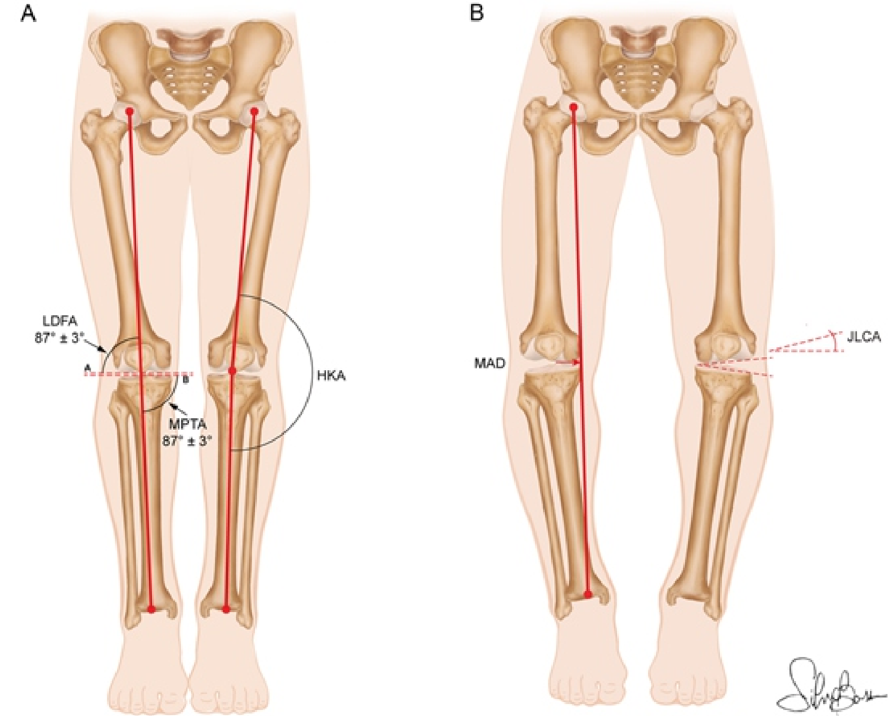

Figure 1: Main axes of the lower limb on the frontal plane; a) on the right leg is represented Mikulicz line passing through the Fujisawa point, Medial Proximal Tibial Angle (MPTA) = 87° ± 3° and Lateral Distal Femoral Angle = 87° ± 3°, on the left leg is represented the Hip Knee Angle (HKA); b) on the right leg is represented Mechanical Axis Deviation (MAD) and Joint Line Convergence Angle (JLCA) on the left one.

of the procedure should be recommended.

The clinical examination consists of the evaluation of gait, range of motion (ROM), anteroposterior and varus-valgus stability, genu recurvatum, flexion contracture, or thrust sign presence.

Ligamentous or meniscal tears and cartilage status should be investigated on magnetic resonance imaging (MRI).

History of previous trauma or meniscectomy, ACL reconstruction, or cartilage procedures must be documented.

Pre-operative planning should be done on a full-length anteroposterior radiograph with double-leg standing and posteroanterior views in 45° of flexion (Rosenberg view), lateral and skyline views [6].

Lower limb axes can be pathologically altered in the frontal, sagittal and/or transverse plane.

On the frontal plane, the main axis that surgeon should consider are: the mechanical axis (Mikulicz line) passing through the Fujisawa point, located at 62% across the width of the tibial plateau from medial to lateral [7], mechanical axis deviation (MAD), hip-knee-ankle (HKA), medial proximal tibial angle (MPTA), lateral distal femoral angle (LDFA) and joint line convergence angle (JLCA) (Fig.1).

On the sagittal plane, the posterior tibial slope and patellar height should be carefully evaluated. Furthermore, wear due to anterior tibial subluxation can be associated with ACL lesion [8]. Stress radiographs may be helpful to assess latent soft tissue laxity of the collateral knee ligaments. Latent soft tissue laxity is defined as the amount of soft tissue that can be extended to valgus or varus from the weight-bearing position, and it is calculated by subtracting the JLCA on weight-bearing standing radiographs from that on stress radiograph. In a recent study, Lee et al. found that latent medial laxity was the most crucial factor associated with postoperative JLCA changes. JLCA changes had a statistically significant correlation with latent medial laxity (R=0.6) and a statistically borderline significant correlation with correction angle (R = 0.2). These imply that the postoperative JLCA change increased by 0.6° per 1° increase in latent medial laxity and increased by 0.2° per 1° increase in correction angle. The JLCA change could be larger in patients with large latent medial laxity or severe varus deformity requiring a large correction, which could lead to unexpected over correction in high tibial osteotomy (HTO). Thus, postoperative JLCA change should be considered in preoperative surgical planning. Target point shifting within the Fujisawa point [7] could be a strategy to prevent over correction, especially in patients with large latent medial laxity [9].

Another important factor to consider is the location of the deformity, which can be intra-articular or extra-articular. This aspect influences the site of the osteotomy. Indeed, deformity correction

Table 1: Indications for Opening-wedge and Closing wedge High Tibial Osteotomies.

Insufficient MCL	Intact MCL
Patella alta	Patella baja
Associated ACL reconstruction	Associated ACL reconstruction
Tibial slope correction	Normal tibial slope
Severe varus deformity with proximal tibial malrotation, idiopathic varus morphotype	Light or moderate deformity, no morphotype alterations
Simultaneous medial arthrotomy	Simultaneous lateral arthrotomy

Abbreviations: ACL Anterior Cruciate Ligament; MCL Medial Collateral Ligament

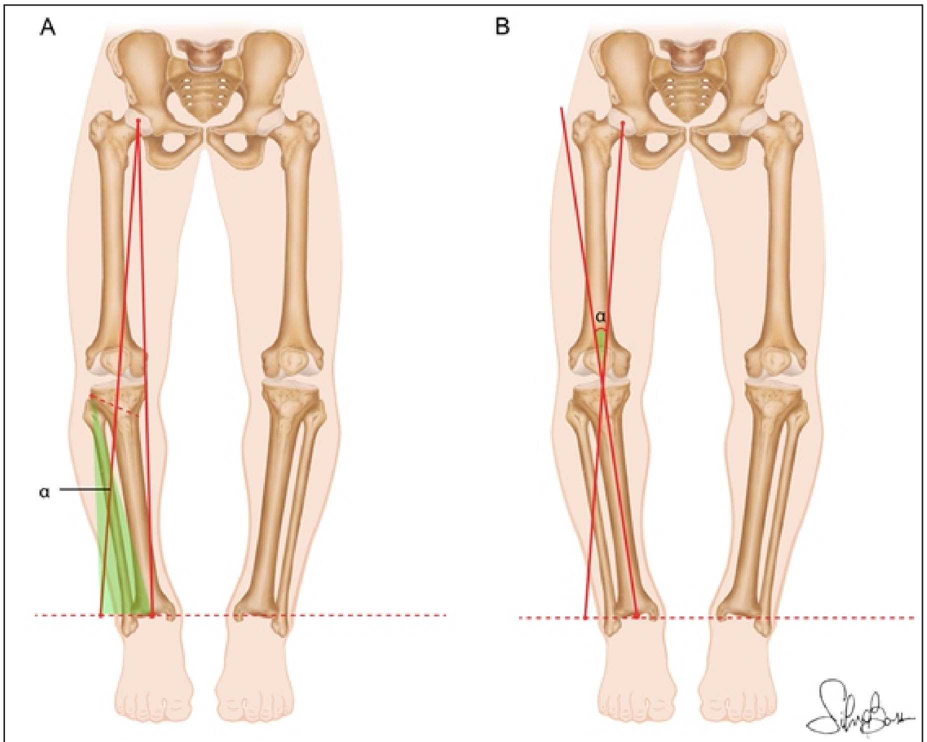

Figure 2: Diagram of the planning method for knee osteotomy according to:
a) Miniaci: the hinge of planned osteotomy is considered as starting point for angle measurement. The angle to correct is included between a line passing through the center of the ankle joint and a line passing to the distal apex of the correct mechanical axis.
b) Dugdale: the angle of correction is included between the mechanical axis of the femur and the mechanical axis of the tibia passing through the Fujisawa point. The amount of bone to be resected to obtain the desired angular correction must be measured at the osteotomy site by reporting the angle obtained from the planning.

should be performed at its source (femur, tibia, or both) and, if possible, at the center of rotation of angulation (CORA). CORA is the angle formed between the intersection of the proximal and distal axis of a deformed bone and it is a measure of the angular deformity.
If osteotomy line passes through CORA, realignment occurs without translation. When the osteotomy is performed at another level than at the CORA, the axis will not only realign by angulation, but translation will occur as well. In that case, correction of the mechanical axis may be achieved but a pathological joint line orientation may be the secondary adverse result.
The goal of correction depends on the patient's morphotype. Neutral alignment is the goal of post-traumatic conditions without knee osteoarthritis. In varus alignment associated with medial compartment osteoarthritis of the knee, the target should be to obtain of some degree of overcorrection to unload the affected compartment [10,11]. In lateral compartment osteoarthritis associated with valgus alignment correction to neutral often sufficiently unloads the diseased compartment. In the case of collateral ligament laxity, only correction to neutral (rather than valgus) alignment should be obtained to avoid overloading the lateral compartment [12].
Several methods for osteotomy planning are described in the literature. The most used are the Miniaci [13] method and Dugdale [6] (Fig.2).
The first considers the hinge of planned osteotomy as a starting point for angle measurement. The angle to correct is included between a line passing through the center of the ankle joint and a line passing to the distal apex of the correct mechanical axis.
In Dougdale's method, the angle of correction is included between the mechanical axis of the femur and the mechanical axis of the tibia passing through the Fujisawa point.
The amount of bone to be resected to obtain the desired angular correction must be measured at the osteotomy site by reporting the angle obtained from the planning [6,13].

Types of Osteotomy

The two most common types of knee osteotomies are HTO, a reshaping of the shin bone, and femoral distal osteotomy (DFO), a reshaping of the thigh bone. HTOs are commonly used to correct varus deformities, while DFOs aim is to correct valgus deformities around the knee.
Regarding HTO, various techniques have been described including closing wedge osteotomy, opening wedge osteotomy, dome osteotomy, progressive callus distraction, and chevron osteotomy.
Varus deformities can be corrected through opening-wedge HTO and closing-wedge HTO.
Medial opening-wedge HTO is usually performed in case of severe varus deformity with proximal tibial malrotation, as is often seen in patients with idiopathic varus morphotype. Furthermore, this type of osteotomy can be used in case of associated ligament laxity, in order to correct the tibial slope.
Instead, a lateral closing-wedge HTO is performed for OA patients with no morphotype alterations and with light or moderate deformity and the tibial slope doesn't have to be modified [12]. (Table 1)
The additional factors influencing the choice of osteotomy technique are patellar height, age, bone and tissue quality, limb length, functional demand, previous incisions, and psychological aspects. Patients with a high risk of nonunion such as smokers, diabetic or

Table 2: Adavantages and disadvantages for Opening-wedge and Closing wedge High Tibial Osteotomies

Opening-wedge HTO	Closing-wedge HTO
Faster surgery	Longer surgery
Higher precision	Lower precision
Risk of the saphenous nerve lesion	Risk of the peroneus nerve lesion
No limb shortening	Possible limb shortening
No loosening of posterolateral structures	Risk of posterolateral structures lesions
Bone graft necessary in case of high correction	No graft necessary
Longer rehabilitation	Faster rehabilitation
No tibial shape alteration	Modifies tibial shape

Table 3: Advantages and Disadvantages for Lateral Opening Wedge and Medial Closing Wedge Distal Femoral Varus Osteotomy.

Distal Femoral Varus Osteotomy (DFVO)	
Lateral Opening Wedge Technique	**Medial closing wedge Technique**
Single bone cut	Better union rate
Avoidance of vascular structures	Risk of neurovascular lesions
Delayed union/nonunion	Better bone healing
Better control of the amount of correction	Suboptimal control of the amount of correction

heavy patients, should be a strong candidate for closing-wedge osteotomy.

The choice of the appropriate technique for each patient must be taken on the account of advantages and disadvantages of each technique. Medial opening-wedge HTO advantages include preservation of the tibiofibular joint (the technique does not require fibular osteotomy), no risk of neurovascular complications, loosening of posterolateral structures, or limb shortening, therefore maintaining of the normal anatomical tibial bone shape after the procedure.

The disadvantages are the potential for loss of correction due to unstable fixation, longer rehabilitation, higher nonunion rates, higher need for bone grafting, and an increase of patella baja incidence.

Lateral closing-wedge HTO does not necessitate bone grafting, permits earlier weight-bearing has less risk of nonunion and loss of correction [2]. (Table 2)

However, closing-wedge osteotomy alters the tibial shape, which can complicate successive arthroplasty. Additionally, the need for fibular osteotomy increases the risk of non-union and peroneal nerve palsy.

Isolated lateral compartment OA is less common than medial OA and can be treated at the proximal tibia or, more commonly, at the distal femur. Valgus correction on the tibial side has been disapproved because a varus-producing HTO can generate an obliquity of the joint line, which is rare with correction on the femoral side. Distal femoral varus osteotomy can be performed with medial closing wedge or lateral opening wedge techniques.

The advantages of the opening wedge technique over the medial closing wedge technique include a single bone cut, avoidance of vascular structures, and supposedly better control of the amount of correction [14]. Disadvantages comprise the risk for delayed union or nonunion given that 2 bone-graft interfaces must heal and irritation of sensitive lateral knee structures by hardware or surgical trauma [15]. (Table 3)

Isolated osteotomy vs combined procedure

High tibial osteotomy is a safe procedure for young patients who are suffering from early osteoarthritis. Papachristou et al. found medium-term good results and they concluded that corrective osteotomy redistributes the forces toward the normal side, however, normal values were never attained [16].

According to them, HTO buys time and allows the patients to lead a normal life for 10–15 years. Flecher, Gstöttner, Akizuki, Hui et al. also found good long-term survival results of closing-wedge HTO in their study [17-20]. Laprade found that opening-wedge HTO significantly improved the subjective and objective clinical outcome scores along

Table 4: Isolated Osteotomy procedures and their clinical outcomes.

Author	N. of patients	Years of follow-up	Procedure performed	Clinical outcomes
Papachristou (2006)	44 knees	Mean 10 years	Closing-wedge HTO	The average postoperative HSS Knee score was 83.5 points for patients with excellent or good results where the preoperative score was 52 points. Survivorship rate of 80% and 66% at 10 and 15 years respectively, and over 52.8% at 17 years of follow-up.
Flecher (2006)	301 knees	Mean 18 year	Closing-wedge HTO	The survival rate was 85% at 20 years with revision as the endpoint. Knee function was considered satisfactory by 77% of patients.
Gstöttner (2008)	134 knees	18 year	Closing-wedge HTO	Survival rate was 94% after 5 years, 79.9% after10 years, 65.5% after 15 years, and 54.1% after 18 years.
Akizuki (2008)	159 knees	Mean 16.4 years	Closing-wedge HTO	Kaplan-Meier survival was 97.6% at 10 years and 90.4% at 15 years. HSS knee score was excellent and good in 73.7% cases.
Hui (2011)	394 patients	Minimum 15 years follow up	Closing-wedge HTO	Survival at 5, 10, and 15 years was 95%, 79%, and 56%, respectively. Multivariate regression analysis showed that age under 50 years (P = 0.001), BMI less than 25 (P = 0.006), and ACL deficiency (P = 0.03) were associated with better odds of survival. Mean Oxford Knee Score was 40 of 48 (range, 17-48). 85% of the patients were satisfied.
Laprade (2012)	47 patients	minimum of 2 years follow-up	Opening-wedge HTO	Modified Cincinnati Knee Scores improved significantly from 42.9 preoperatively to 65.1. Significant improvement in malalignment. The Insall-Salvati index decreased from 1.03 to 0.95 (P < 0.05), and posterior tibial slope increased from 9.4° to 11.7° (P < 0.05).
Floerkemeier (2013)	386 patients	Mean 3.6 year	Opening-wedge HTO	The mean Oxford Knee Score was 43 points. Lower score observed in patients with a higher preoperative medial cartilage lesion. No correlation between patient age and the Oxford Knee Score.
Bonnin (2013)	139 patients	mean 50 months	Closing-wedge HTO in 88 patients Opening-wedge HTO in 51 patients	63% found their knee "normal," and 62% felt that their activities were limited by their knee. 56% were as active as before the intervention and 98% of them were satisfied. Those who were not as active as they thought, 51% were satisfied (P < 0.0001).
Liu (2019)	38 patients	minimum of 2 years	Opening-wedge HTO	88.2% of return to sport by 7.5 months postoperatively but only 41.2% were able to return to preinjury level of participation. 40% of patients underwent knee arthroplasty by 6.1 years post-operatively hence HTO is not a definitive procedure.
Berruto (2020)	94 knees	Mean follow-up 11.9 ± 7.2 years.	Closing-wedge HTO	HSS Score increased significantly from 70.8 ± 10 to 93.2 ± 9.1 (p < 0.05). VAS score significantly decreased from 7.9 ± 1.4 to 1.6 ± 1.1 (p < 0.05). HKA angle decreased from 6.9° ± 3.5 to 2.6° ± 2.6 (p < 0.01), tibial slope decreased from 10.1° ± 1.4 to 6.8° ± 2.1 (p < 0.05). Survivorship rate was 92% at 10 years, 82% at 15 years and 80% at 20 years.

Abbreviations: HTO High Tibial Osteotomy, HSS Hospital for Special Surgery, ACL Anterior Cruciate Ligament, BMI Body Mass Index, HKA Hip Knee Ankle

Table 5: Combined HTO and cartilage procedure or meniscal procedure and their clinical outcomes.

Author	N. of patients	Years of follow-up	Procedure performed	Clinical outcomes
Sterett (2010)	106 knees		medial opening-wedge HTO and microfracture	At 5 years, survivorship was 97%. At 7 years, survivorship was 91%. After combined HTO/microfracture; patients had a mean delay of 81.3 months for arthroplasty procedure.
Bode (2015)	40 patients	mean follow-up of 60 months	ACI and HTO	Significant decrease in VAS from 6.7 ± 1.9 points to 2.2 ± 1.3 points. Lysholm score improved from 54.4±18.9 to 76.2±19.8 points. The mean KOOS subscales were 81.4 ± 18.0 for pain, 81.3 ± 14.0 for symptoms, 87.6 ± 16.2 for activity in daily living, 66.7 ± 22.8 for function in sport and recreation, and 55.5 ± 22.0 for knee-related quality of living. Revision surgery required in four cases (failure rate 10 %).
Schuster (2015)	91 knees	a minimum follow-up of 5 years	medial opening-wedge HTO combined with a chondral resurfacing procedure	The survival rate was 95.2% at 5 years. Subjective IKDC scores significantly improved from 45.1 ± 11.6 to 67.2 ± 14.4 points after 5 years (P < .001). 94.9% of cases were satisfied with the result after 5 years.
Hsu (2018)	17 patients	minimum of 2 years follow-up	HTO + OCA	88% had intact allografts with a mean survival of 8.1 years (SD 3.3) also mean pain and function scores improved significantly and IKDC total scores improved significantly from 40.9 ± 15.4 to 75.5 ± 24.0 (P = 0.003). 92% of patients were satisfied with the results of the surgery. 12% failed at a mean of 9.3 years.
Agarwalla (2020)	28 patients	minimum of 2 years follow-up	HTO + OCA	88.5% of patients returned to the same level of occupational intensity by 3.5 ± 2.9 months postoperatively. A high rate of return to work (RTW) (96.2%) by 3.5 ± 2.9 months postoperatively and RTW depends on occupational intensity.
Marcacci (2013)	43 patients	Mean 3 years follow-up	15 osteotomy and osteochondral biomimetic scaffold, 11 osteotomy and meniscal scaffold, 9 osteotomy and meniscal allograft, 8 with both cartilage and meniscal reconstruction	subjective IKDC improved from 47.3 to 79.6 (p < 0.0005), VAS improved from 6.1 to 2.3 (p < 0.0005), sport activity level showed a significant improvement (Tegner score) from 2 to 4; p < 0.0005. A positive outcome obtained in all the subgroups. Higher clinical improvement in patients under the age of 40 years (IKDC subjective 84.4 ± 13.2 vs 76.5 ± 17.3; p = 0.03).
Liu (2019)	22 patients	Minimum 2 years follow up	HTO with concomitant medial MAT	High rates return to sport (87.5%) and return to work (100%) by 9.7 months and 3.1 months, respectively.

Abbreviations: ACI Autologous Chondrocyte Implantation, VAS Visual Analog Scale, KOOS Knee Injury and Osteoarthritis Outcome Score, IKDC International Knee Doc

with the correction of malalignment [21]. Floerkemeier et al. found favorable midterm results after opening wedge HTO in varus osteoarthritis, even in older patients with a high degree of cartilage damage [22]. Liu et al. concluded that isolated opening-wedge HTO provides a high rate of return to the sport in patients with medial osteoarthritis and varus deformity, however, only a fraction of patients returned to their preinjury level [23]. Similar results were also found by Bonnin et al. [24] According to Berruto et al., HTO is a valid option for medial osteoarthritis treatment, with successful results in both clinical and radiological outcomes [25].

Improved meniscal and cartilage restoration techniques renewed interest in knee osteotomies in young patients with knee pain and joint surface defects [26]. In the last decade, the majority of osteotomies have been performed in combined with cartilage repair, meniscal transplantation, and ligament reconstruction. (Table 4)

HTO + Cartilage procedures

Cartilage restoration techniques used in conjunction with HTO are effective for improving function and relieving pain because there is likely a synergistic relation between cartilage restoration and knee realignment. Improved mechanical axis alignment results in improved cartilage healing and this improved cartilage status is responsible for increased pain relief following HTO [27,28]. In the absence of coronal plane deformity, an isolated chondral resurfacing procedure might be performed, but when deformity may result in a mechanical overload of the affected compartment then the isolated procedure is contraindicated. Before any cartilage repair procedure, a malalignment correction is mandatory, hence a combined approach appears sensible [29].

Indication for concomitant HTO and cartilage restoration procedure is grade 2 or 3 chondral lesions in the medial compartment associated with a varus knee, with an intact lateral compartment with stable joint and without significant limitation of movement, and without patellar malposition in the young and active patient [30]. HTO creates a suitable environment for cartilage restoration by offloading the damaged cartilage. Microfracture is the most commonly used cartilage restoration procedure while autologous chondrocyte transfer is the second most widely used procedure [31]. HTO and concomitant cartilage procedures may

Table 6: Combined Procedure of ACL and HTO and their clinical outcomes.

Author	N. of patients	Years of follow-up	Procedure performed	Clinical outcomes
Bonin (2004)	30 knees	12 years mean followup	Single-stage combined ACL reconstruction with valgus HTO	Only 5 knees had progressed one arthritis grade. 14 patients returned to intensive sports, and a further 11 played moderate sports. The mean difference in anterior tibial translation with the opposite normal knee was 3 mm.
Zaffagnini (2013)	32 patients	Mean 6.5 ± 2.7 years	Single-bundle over-the-top ACL reconstruction with concomitant closing-wedge lateral HTO	Subjective and objective IKDC, Tegner Activity Level, EQ-5D, VAS for pain, and AP laxity assessment with KT-1000 arthrometer; significantly improved from pre-operative status to final follow-up.
Trojani (2014)	29 Patients	mean 6 years	ACL reconstruction combined with medial opening wedge HTO	Combined ACL reconstruction and valgus HTO relieved pain in 70% of cases and restored knee stability enabling a return to the sport in 80%. 97% of patients were satisfied by outcomes.
Mehl (2017)	52 patients	mean of 5.8 years	Symptomatic varus osteoarthritis and deficiency of the ACL in all patients. 26 patients had HTO alone (group 1) while 26 patients had single-stage HTO and ACL reconstruction (group 2)	Pain improved in 81% of patients while instability improved in 79% without significant group difference. Significant worse results in group 1 for the Lysholm score and the IKDC score. No group difference for the KT-2000 examination. A significant post-operative increase of radiographic OA in both groups without significant group differences.
Schneider (2020)	36 knees	mean follow-up of 10 ± 5.2 years	Simultaneous ACL reconstruction and opening wedge HTO	80% of patients returned to the sport, 31% returned to the sport at the same level, and 17% to competitive sports. Subjective IKDC score improved by 30.2 points (p<0.001) Lysholm scores were 82 ± 14.1 at the final follow-up. 88% of patients were satisfied and a significant decrease in mean Tegner activity level (p < 0.01). The mean preoperative mechanical axis was 4.2° ± 2.6° varus and 0.8° ± 2.7° valgus at follow-up.
Schuster (2020)	21 Patients	a minimum follow-up of 10 years	Medial opening-wedge HTO combined with ACL reconstruction and chondral resurfacing (CR) procedure	At the final follow-up, survival was 100%. Subjective IKDC score improved from 47 ± 11 to 70 ± 16 (p < 0.001). At the final follow-up, the Oxford Knee Score was 40 ± 7 and pain-level significantly decreased from 7.5 ± 1.0 to 2.9 ± 2.3 (p < 0.001). All patients were satisfied with the result.

Abbreviations: ACL Anterior Cruciate Ligament, HTO High Tibial Osteotomy, IKDC International Knee Documentation Committee, VAS Visual Analog Scale, AP Anteroposterior, OA Osteoarthriti

potentially delay the need for TKA. Sterett et al. found more than 90 % survivorship at 7 years and a delay for knee replacement in active patients treated with HTO and concomitant cartilage procedures [32]. Bode et al. found that concomitant autologous chondrocyte implantation (ACI) and HTO had significantly higher survival and better clinical outcome compared with ACI alone. Moreover, cartilage lesions treated with HTO even with varus deformities of <5° leads to a reduced rate of reinterventions and longer survival rates [33].

Agarwalla et al. found that HTO with concomitant osteochondral allograft transplantation of the medial femoral condyle leads to a return to work in the majority of the patients with focal chondral deficiency and varus deformity. However, timing depends on the intensity of the work [34]. Hsu et al. also found this procedure safe and effective in properly selected patients [35].

Platelet-rich plasma (PRP) or mesenchymal stem cells (MSCs) can also be added to HTO which results in improve cartilage healing. Koh et al. found in their study that HTO along with MSC improved cartilage healing more than PRP as identified by second-look arthroscopy. Also, patients with MSC augmentation showed improved outcome measures [36].

HTO+Meniscal allograft transplantation

Meniscal allograft transplantation (MAT) is an effective treatment to decrease pain and improve knee function in patients who are still symptomatic after a meniscectomy [37]. MAT is often indicated in young, active patients with total or subtotal meniscal damage [38]. Concomitant HTO may improve clinical outcomes following MAT by relieving pressure in the medial compartment. Verdonk et al. found in their study that HTO with concomitant medial meniscal transplant resulted in an improvement in pain and function as well as a cumulative survival rate and duration of 83.3% and 13.0 years, respectively [39]. Liu et al. reported high rates of return to sports (87.5%) and return to work (100%) in medial meniscal deficiency and varus deformity cases, which were treated by HTO plus MAT. However, a return to high-intensity activities may be unlikely or delayed. Marcacci et al. also found similar results in their integrated biological and biomechanical approach and they found greater clinical and subjective improvement in younger patients [40].

Therefore, HTO with concomitant medial MAT is an appropriate treatment option for younger, active patients who wish to continue an active lifestyle. (Table 5)

HTO + ACL Reconstruction

Chronic ACL lesions may cause a medial meniscal tear. Meniscectomy may require for this meniscal tear, which may cause medial compartment osteoarthritis and progressive varus malalignment of the lower extremity. On the other hand, severe varus malalignment may compromise the ACL function or increase the risk of failure of the reconstruction. Moreover, an ACL-deficient knee combined with a varus alignment can accelerate the progression of arthritis. Therefore, combined ACL reconstruction and HTO is a good option for such complex patients, who are usually young. Zaffagnini et al. found in their study that concomitant ACL reconstruction (primary/revision) with closing-wedge HTO in chronic ACL deficiency, varus alignment, and initial medial osteoarthritis patients, reduced pain, improved knee function, and laxity [41]. Bonin et al. found in the long term follow-up of 12 years that concomitant ACL reconstruction with HTO has low morbidity, controls anterior laxity, allows many patients to return to sports, and not associated with a higher increase of OA [42]. Similarly, Trojani et al. and Schneider et al. also found that combined procedure relieved pain and restored knee stability enabling a return to the sport in the majority of patients [43,44]. Mehl reported significantly worse Lysholm and IKDC scores in patients treated by HTO alone compared with single-stage HTO and ACL reconstruction for ACL deficit knee with symptomatic varus osteoarthritis [45]. Schuster et al. found excellent results in a long-term follow-up in selected young patients even in severe osteoarthritis by performing a combined approach medial opening wedge HTO with ACL reconstruction and a chondral resurfacing (CR) procedure (abrasion/microfracture) [46].

If not corrected during primary ACL reconstruction, an excessive posterior tibial slope (>12°) may results in the anterior shift of the tibia's resting position, thus increasing anterior translational forces on the ACL which may lead to re-rupture of ACL [47]. Moreover, this sagittal imbalance of the tibia can lead to abnormal loading of a knee compartment, resulting in damage to menisci and articular cartilage [48]. HTO corrects the pathological posterior tibial slope and this reduced posterior tibial slopes may have a protective effect on the ACL graft, by reducing anterior laxity thereby reducing the re-rupture rate [49]. Gupta et al. found in their systematic review that HTO for revision ACL surgery produces good post-operative functional outcomes, low complication rates, and no re-ruptures. According to them posterior slope of more than 12° or severe varus malalignment were the main indications for combined HTO with ACL revision [50].

HTO also correct the varus malalignment and delay the progression of osteoarthritis by controlling anterior tibial translation and offloading the medial compartment of the knee. (Table 6)

Conclusion

Osteotomy around the knee represents a suitable treatment for the biological restoration of knee function and to delay the need for TKA. Understanding it's rational and the possibility to combine it with other procedures allows us to obtain the most clinical benefit for the patient.

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