Chapter

High Tibial Osteotomy

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Abstract

To address lower limb malalignment with concomitant medial compartment osteoarthritis, meniscal deficiency, focal chondral defects, and ligamentous instability, high tibia osteotomy (HTO) is a reliable treatment option. In order to achieve a good long-term outcome with HTO, a comprehensive history and physical examination, together with a meticulous patient selection and careful pre-operative planning, and selection of the appropriate fixation technique and rehabilitation protocol are paramount.

Keywords: medial compartment osteoarthritis, chondral defect, high tibial osteotomy, medial opening wedge, lateral closing wedge, survival rates, complications

1. Introduction

Cartilage degeneration of a particular compartment of the knee joint is usually the result of overloading of medial compartment which is associated with the malalignment of the lower extremity. In other words, cartilage degeneration is an inevitable result of lower extremity malalignment and it is associated with clinical symptoms including pain and gait difficulty. In addition to arthritis, rickets, Blount disease, or tibial plateau fractures are other reasons for lower limb deformity, but we will not further mention them here because they are irrelevant to this chapter. In order to prevent the progressive cartilage degeneration followed by amelioration of the symptoms, re-alignment osteotomies, which have the potential to unload the compartment while preserving the native joint, are generally applied. Considering the relative young age of these patients with unicompartmental arthrosis, in order to delay the arthroplasty, re-alignment osteotomies, while being technically challenging constitute the most important treatment modality by providing earlier return to high-level activities in contrast to arthroplasty. Osteotomies might also be applied with procedures including meniscal repairs, ligamentous reconstructions, or cartilage regenerating procedures, because of augmenting the success rates of these co-applied procedures. Indications for re-alignment osteotomies have been expanded recently as a result of high activity levels of the relatively older patients. Meanwhile, an optimization of the re-alignment osteotomies occurred as a result of the modified surgical instruments and techniques, leading to more reliable outcomes.

In young and active patients, it is important to preserve the medial compartment of the knee and provide adequate cartilage coverage to prevent a premature arthritis and to delay the arthroplasty as much as possible [1]. High tibial osteotomy (HTO) for varus deformity is one of the most common types of osteotomies for the re-alignment of the knee.

First HTO was performed by Jackson and Waugh in 1958, while they defined the technique as a ball and socket osteotomy inferior to anterior tibial tuberosity and at the middle third portion of the fibula [2]. Modifications of the original technique were reported with a success rate of 85% [3]. In 1965, Coventry reported his results regarding long-term outcomes, which was not very promising and made several publications in the following years [4]. The introduction of the blade plate for maintaining correction and allowing early motion was undertaken by Koshino. Opening wedge technique was later introduced by Hernigou and Debeyre with medial approach, where bone grafts and plates were used in order to have a stable fixation, while they recognized the importance of maintaining the sagittal slope while the coronal plane was being corrected [5, 6]. In the beginning of 1980, Maquet described the tibial dome osteotomy. The modern HTO is actually a variation of the Coventry osteotomy. HTO's high popularity between 1960 and 1980, showed a slow decline afterwards as a result of many reported good outcomes of total-unicondylar knee arthroplasty that changed the surgeons' preferences.

HTO is regaining popularity, especially in young and active patients with high expectations for physical activities and increased life expectancy, in order to preserve the native joint together with bone stock, cartilage covering and proprioception, which are compromised with unicompartmental knee arthroplasty, in addition to its allowance to relatively limited physical activities [1, 7, 8]. The currently used plates are providing very stable osteosynthesis by preserving the periosteal blood supply; while there are also new biomaterials and bone substitutes that prevent many complications related to iliac crest graft harvest [9–11]. Meanwhile, HTO became a more popular option for young and active patients as a result of the improvements regarding the surgical technique, fixation devices, and fewer complications accompanied with a meticulous patient selection [12–15].

HTO, as a re-alignment osteotomy is applied to transfer the medially deviated mechanical axis to lateral toward the midline of the knee to unload the medial compartment and delay the process of osteoarthritis (OA) [11, 13, 14]. The first aim of HTO is to eliminate or reduce pain, by translating loads to the contralateral (femorotibial) compartment as a result of the deformity correction; while some studies has reported that the regenerative process was beginning after the accomplishment of re-alignment [16–18].

2. Indications

Careful pre-operative planning and strict indication criteria are paramount in order to have a successful outcome in the long term [1, 11].

Indications of HTO can be categorized as physical and radiological. Physical indications include: *an age between 40 and 70 years; a well-localized pain at the medial joint line; an arc of flexion more than 90° and, a lack of extension less than 10°; normal or correctable ligamentous status, while anterior cruciate ligament [ACL] or posterior cruciate ligament [PCL] insufficiency is not a contraindication; non-reducible deformity; and an active lifestyle* [7, 11].

Physical contraindications comprise: *any inflammatory disease, obesity, smoking, history of meniscectomy in the contralateral compartment, osteoarthritis in the contralateral compartment, and a tibial subluxation more than 1 cm.*

Radiological indications include: *no contralateral femorotibial joint space narrowing or patellofemoral joint space narrowing, partial or complete joint space narrowing in one compartment, significant symptomatic chondral injury to the patellofemoral or lateral compartments, tricompartmental arthritis and extra-articular deformity more than 5°* [1, 14]. To accurately assess the lateral compartment MRI could be very helpful.

Controversial contraindications regarding the HTO procedure include: *age > 60; obese females; flexion less than 120°, flexion contracture > 5°, or fixed flexion deformity; patellofemoral arthritis; accompanying severe extra-articular deformity* [11, 14].

HTO was recently suggested to be included in joint preservation surgery, to unload a cartilage restoration site (autologous chondrocyte implantation [ACI], osteochondral autograft or allograft, microfracture), and to correct the sagittal slope in cruciate ligament insufficiency [1, 8, 17]. When HTO is performed before medial compartment, arthritis has become severe and subchondral bone has been exposed, superior clinical and outcomes can be achieved [19, 20].

We would like to underline some important scenarios that should be meticulously assessed. Patients with anterior knee pain may get worse after the HTO procedure providing a coronal plane correction that can worsen their symptoms. Patients should be carefully explained, that the recovery from an HTO is time consuming and requiring commitment of the patient. Patients should be explained, that HTO procedure's post-operative rehabilitation protocol typically requires a period of protected weight-bearing followed by extensive lower limb muscular training. Patients should understand that an average of 6 months is needed to have a total recovery to a pain-free state of full activity. It is also very important that, pre-operatively, patient expectations should be thoroughly discussed and managed appropriately.

Indications of HTO might differ according to the geographical region. Patients older than 60 of age are typically offered total or unicompartmental knee arthroplasty over an HTO in the United States, while outside the United States, HTO is frequently performed in older patients, who are fit and active, and are explained that they may not obtain total symptom relief [1, 8].

It should be noted that the ideal patient for the application of HTO is a relatively young, active, and non-smoking patient, for whom arthroplasty should be prevented or delayed. As described above, obesity was also reported as a contraindication in old patients, because of the increased stresses that the osteotomy site must support; while it is a relative indication in younger patients in whom arthroplasty is indicated [1, 8].

A large-scale population-based study looking at 2671 patients who had undergone an HTO before conversion to a TKA found that certain factors lowered HTO survival rates, including accompanied ligament injuries, prior meniscectomy, older age, and female sex were reported to lower the HTO survival rates in 2761 patients, who underwent HTO before conversion to total knee arthroplasty [21].

3. Patient history and physical exam

A thorough history and physical exam are paramount before proceeding with HTO. As a result of that, patients with a prior traumatic knee injury and patients with a new onset of medial compartment arthritis could be distinguished. Previous trauma may be associated with other concomitant ligamentous and cartilaginous injuries. In every patient, in order to meet the expectations, the levels of activity, and overall health should be precisely noted.

Physical exam starts with the observation of patient's gait and stance, especially to assess varus thrust, accompanied with the presence of lateral collateral ligament insufficiency. Patients with varus deformity at the knee joint can be identified by observing them standing and walking. However, in cases of large body habitus, observation alone might not be very reliable. Examination of gait is critical regarding the decision with HTO. In patients with varus deformity at the knee joint, medial compartment is overloaded which creates an increased knee adduction moment, leading to increased stresses of the tensions of lateral ligamentous structures. In the presence of varus malalignment at knee joint, lateral ligamentous insufficiency may develop over time, and can even progress to varus recurvatum deformity associated with anterior cruciate ligament (ACL) insufficiency requiring ligament reconstruction in addition to HTO procedure [1, 11]. Joint instability including insufficiency of collateral and cruciate ligaments, any ankle deformity and limb length discrepancy should be considered for concomitant or staged surgery [22, 23].

4. Radiographic evaluation

A complete radiographic evaluation comprises the following X-rays:

- A full-length, three-joint (bilateral hip to ankle on the same cassette) weight-bearing view in full extension with the feet in a neutral position to evaluate the alignment;

- A 45° flexion posteroanterior view to evaluate any narrowing in the posterior femorotibial compartment;

- A lateral view to measure patellar height and assess the patellofemoral joint (PFJ);

- Stress views are mandatory when physical exam reveals ligamentous laxity,

- The tibia bone varus angle (TBVA) is measured on AP radiograph and TBVA > 5° is a good prognostic factor after osteotomy

- A skyline view for detailed evaluation of the patellofemoral joint [1, 8, 11].

Indices regarding the pre-operative patellar height (Caton-Deschamps index, modified Insall-Salvati index, Blackburne-Peel index) should be calculated because both opening and closing wedge HTOs have had the potential to result in patella baja. Therefore, patients with pre-existing patella baja should be evaluated very carefully before performing the HTO procedure [24, 25].

To establish the posterior tibial slope baseline, a lateral radiograph should be obtained. Because of the anatomical-triangular shape of tibia, a medial opening wedge osteotomy comprises a bone cut from anteromedial to posterolateral aspect of the tibia. As the osteotomy site is opened, the tibial slope increases. For a lateral closing wedge osteotomy, the same principle can be used but in a reverse fashion. Considering this type of osteotomy, the bone cut is directed from anterolateral-to-posteromedial, decreasing the tibial slope [1, 23].

In knee joints with cruciate ligament deficiencies, tibial slope changes could directly affect the problem regarding the ligaments. Meanwhile, PCL insufficiency is accentuated by an increased tibial slope, while in an ACL-deficient knee as a result of the decreased tibial slope, the degree of instability is frequently progressed [1, 21, 24]. However, to improve the outcome of HTO procedure, tibial slope adjustments can be applied. To enhance stability in an ACL-deficient knee, tibial slope may be increased, whereas in PCL-deficient knees decreasing the slope can be helpful in establishing stability [1, 21, 24]. We recommend using magnetic resonance imaging (MRI) in order to evaluate the soft tissue problems, including meniscus tears, ligamentoıus injuries, osteochondral defects, or even for the detection of subchondral bone edema.

5. Patient selection

In 2004, ISAKOS (International Society of Arthroscopy, Knee Surgery and Orthopedic Sports Medicine) developed a protocol for the HTO [23]. As a result of that protocol, an ideal patient for HTO is defined by following criteria:

- Malalignment < 15°
- Metaphyseal varus (i.e., TBVA > 5°)
- Full range of motion (ROM) of the knee joint
- Normal, near-normal lateral, and patellofemoral compartments
- No ligamentous instability
- Non-smoker
- Moderately active high-demand patient
- Young (40–60 years of age)
- BMI < 30 (in other words: obesity is a contraindication)
- Isolated medial joint line tenderness
- Some level of pain tolerance

HTO is contraindicated in patients with followings:

- Severe OA of the medial compartment (Ahlback grade III or higher)
- Tricompartmental OA
- Patellofemoral OA
- Age > 65
- Knee ROM < 120°
- Knee flexion contracture > 5°
- Diagnosis of inflammatory arthritis
- Heavy smokers
- large area of exposed bone on tibial and femoral articular surface (>15 × 15 mm)

Good prognostic factors [26–28] regarding the HTO procedure can be summarized as the followings:

- Ahlback grade 0 arthritis of medial plateau

- Age < 50
- Pre-operative TBVA > 5°
- Post-operative obliquity of tibiofemoral joint line in a narrow range close to 0°
- Anatomical valgus alignment of ≥8° at 5 weeks post-op
- Excellent pre-operative Knee Society Score (KSS)

Poor prognostic factors [26–28] regarding the HTO procedure can be summarized as the followings:

- Smoking
- Obesity
- Age > 56 years
- Valgus alignment of ≤5° at 5 weeks post-op
- Post-operative flexion < 120°

Cartilage defect at the medial tibial plateau was shown not to affect the clinical results of HTO procedure by Niemeyer et al. [14] in their study with minimum of 36-month follow-up of 69 patients after medial open wedge high tibial osteotomy (MOWHTO). They also concluded that partial thickness defect in lateral tibial plateau was well-tolerated.

6. Pre-operative decision-making and planning

Before starting with the decision-making process, some important terms regarding the alignment of the lower extremities should be explained [29–32].

- **Mechanical axis:** A line drawn from the center of the femoral head to the center of the knee.
- **Anatomical axis:** A line drawn from the piriformis fossa to the center of the knee joint and a line through the long axis of the tibia.
- **Weight-bearing axis:** A line drawn from the center of the femoral head to the center of ankle joint.

Normal values of the aforementioned axis are [29–32]:

- **Mechanical axis:** 1–3° varus
- **Anatomical axis:** 5–7° valgus
- 6° of valgus between the mechanical and anatomical axes

DOI: http://dx.doi.org/10.5772/intechopen.92887

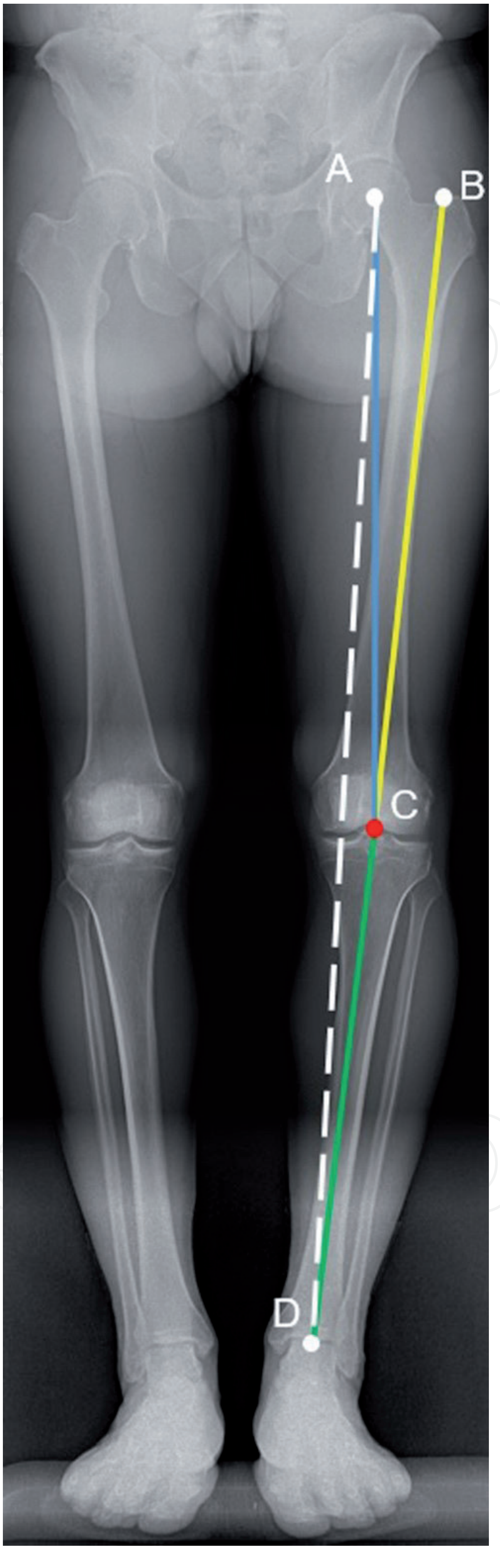

Figure 1.
The main axes of the lower extremity. AC: mechanical axis of femur, BC: anatomical axis of femur, CD: anatomical and mechanical axis of tibia, and AD: weight-bearing axis.

- Weight-bearing line passing through the lateral 30–40% of the tibial plateau
- 60% of the total body weight force passes through the medial compartment.

These measurements are performed on the alignment view (**Figure 1**). As a result of that, the type, location, and most importantly the amount of corrective osteotomy is ascertained. The pre-operative mechanical axis deviation and the degree of medial compartment arthrosis determine the amount of correction needed. Unicompartmental OA was reported to yield clinical symptoms, when the lower extremity alignment was a more than 10° of normal range [33].

If a decision to perform the HTO procedure is established, a medial opening wedge osteotomy or a lateral closing wedge osteotomy can be chosen purely based on the surgeon's decision.

Lateral closing wedge osteotomy, which allow for immediate weight-bearing, possess lower rates of non-union/mal-union, and is theoretically associated with lower risks of increasing the posterior sagittal slope and leading to patella baja was widely used by Coventry in 1960s [34, 35]. However, an exposure violating the anterior compartment of the leg, loss of the present bone stock together with a narrow window for modification once the bone wedge is removed, a possible concomitant fibular osteotomy, and risks associated with peroneal nerve exposure are the disadvantages associated with lateral closing wedge osteotomy.

Recently, as a result of advancements regarding low-contact profile-plated and fixation techniques, bone grafting options and most importantly regarding the technical advantages of the exposure and approach, medial opening wedge osteotomy has gained popularity [10, 13, 14]. By performing the HTO from the medial side and avoiding the lateral side, certain risks associated with the anterior compartment dissection, peroneal nerve exploration and fibular osteotomies can be avoided [8, 13, 14]. HTO procedure, performed as medial opening wedge osteotomy, facilitates correction and allow for fine-tuning in both the coronal and the sagittal planes. However, the risk to increase the sagittal slope and historically higher rates of non-union are the associated disadvantages of this approach [36].

7. Pre-operative planning of correction

The degree of correction is established according to the location of the mechanical axis line through the knee joint [1, 8]. The reference point on the tibial plateau is set at 62.5% of its width as measured from the medial cortex for most cases of genu varum resulting from OA [1, 14, 32]. In order to unload the medial compartment, the mechanical axis is planned to pass lateral to the center of the knee, aiming the lateral compartment [1, 14, 32] (**Figure 2**). A careful pre-operative planning should be undertaken in order to avoid the overloading of the lateral compartment, especially in cases with mild degenerative changes within the lateral compartment [14, 21, 36]. In these cases, massive corrections, or subtle corrections with a concomitant cartilage transplant, the mechanical axis can be moved to the midline of the knee joint to prevent overloading of the lateral side [14, 21, 36].

HTO procedure aims to reach a slight valgus axis to prevent any recurring of genu varum deformity. 3–5° of valgus in the mechanical axis or 8–10° of valgus in the anatomical axis are considered as the primary goals regarding correction after surgery [1, 5, 16, 34]. There is a fine balance between over- and under-correction; while slight varus correction can lead to recurrence of previous deformity, whereas overcorrection and over-deviation of the axis to the lateral compartment

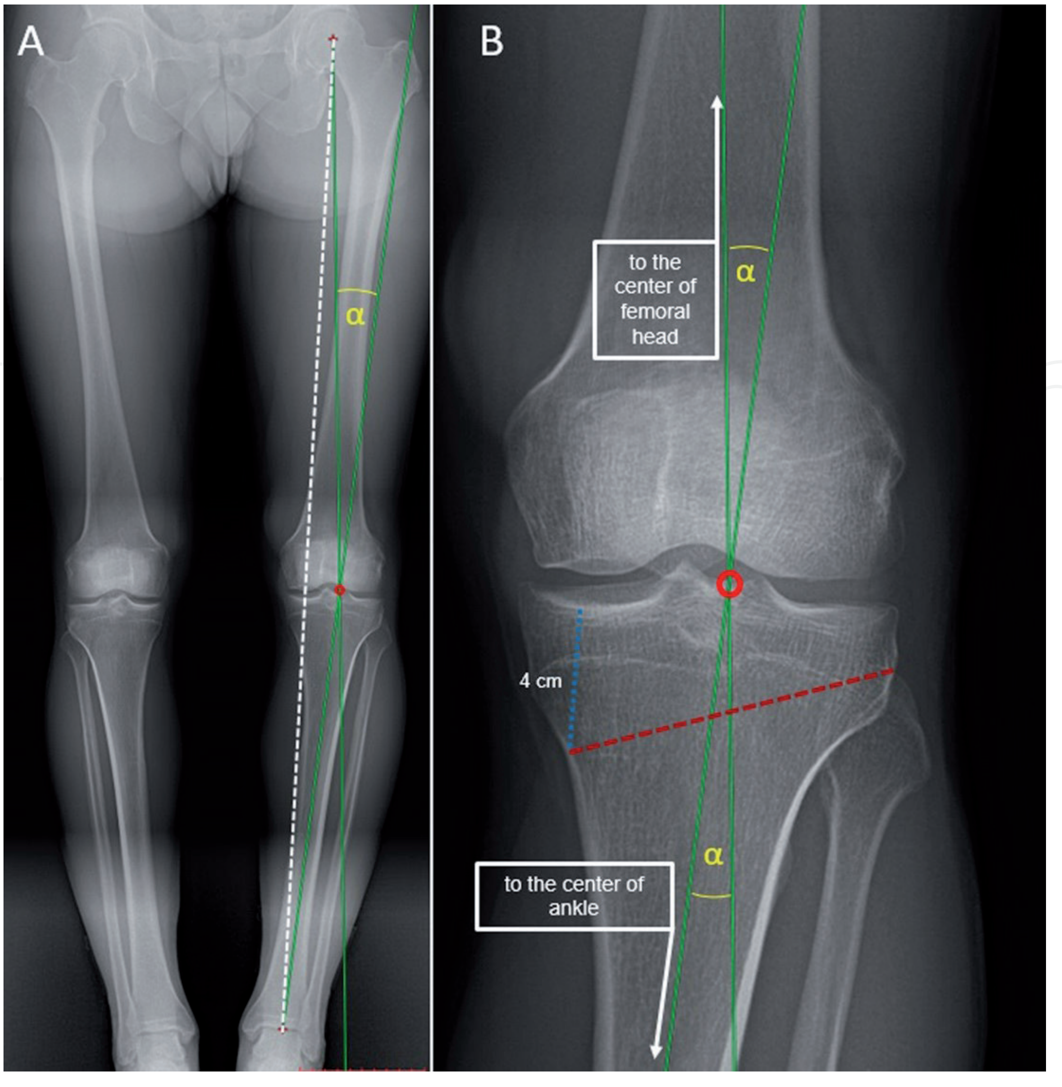

Figure 2.
Pre-operative planning for MOWHTO. (A) The white dashed line represents the weight-bearing axis, whereas the red circle represents the desired point where the weight-bearing axis is planned to pass post-operatively. (B) α, the correction angle, is the angle formed by the mechanical axes of femur and tibia that are aimed to be provided post-operatively. The osteotomy line (the red dashed line) is planned to be started about 4 cm distal to the medial joint line, aiming the tip of the head of fibula.

can cause cartilage degeneration at the lateral compartment, leading to lateral compartment OA [1, 5, 16, 34].

The weight-bearing line (WBL) should pass from 62% of the tibial plateau width when measured from the medial edge point of the medial tibial plateau [32, 37]. The point where WBL intersects the tibial plateau is called as the Fujisawa point [32, 37] (**Figure 3**). Fujisawa point is located slightly lateral to the lateral tibial spine and matches over the mechanical axis with 3–5° of valgus [32, 37]. A line is drawn from this point to the center of the ankle joint and another line from this point to the center of the ipsilateral femoral head is drawn to determine the amount of required correction [32, 37]. The angle measured between these two lines indicates the amount of required correction to re-align the knee joint [11, 32, 37]. The line for the osteotomy is drawn approximately 4 cm below the medial joint line toward the fibular head. This line has to be transferred to the apex of triangle that is created just during planning. The width of the triangle's base corresponds to the amount of correction that is required during a medial open wedge osteotomy [11, 13, 14].

The correction angle for lateral closing wedge osteotomies is calculated using a similar technique. Perpendicular to the axis of tibia and approximately 2 cm below

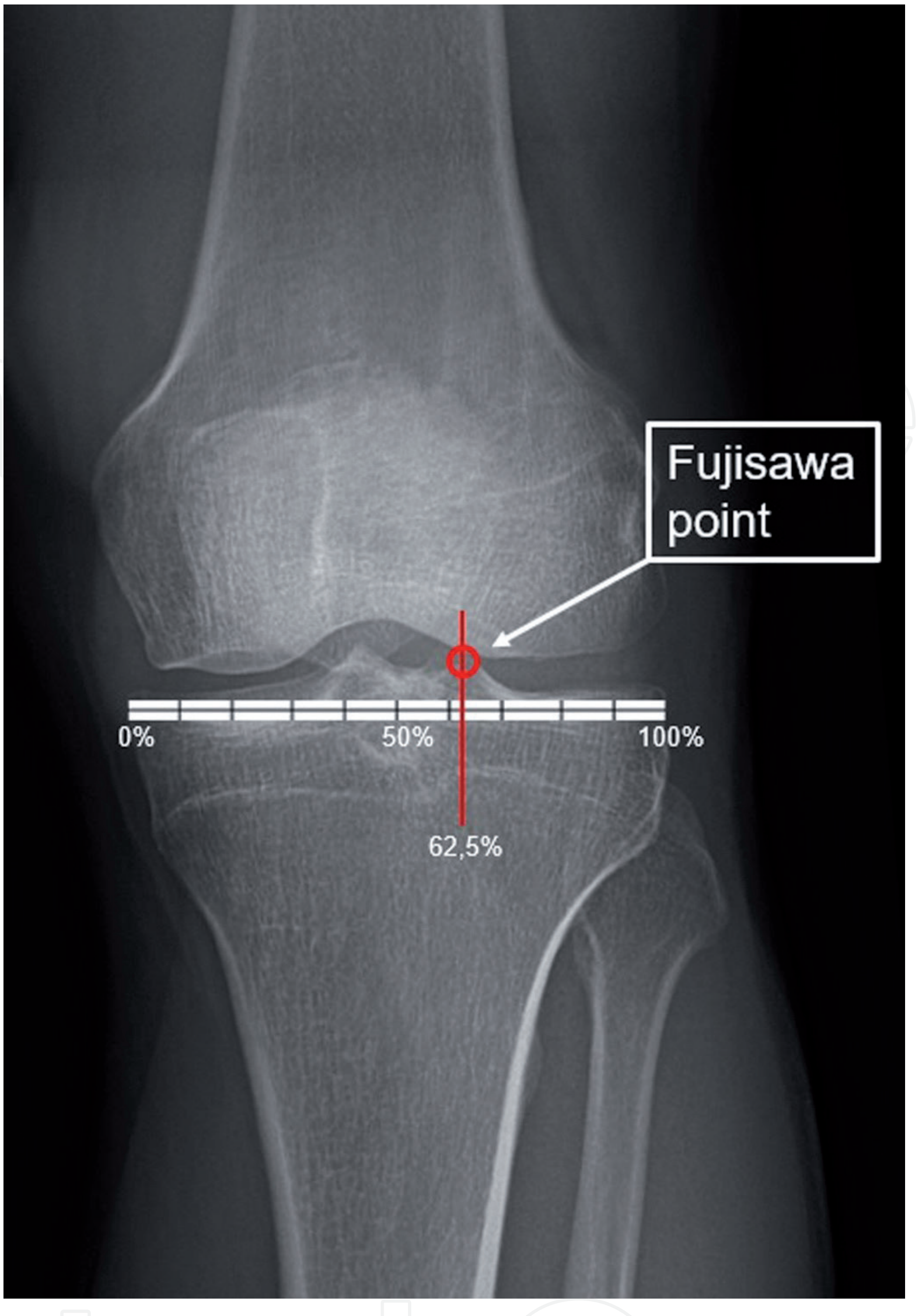

Figure 3.
Picture defining Fujisawa point.

the joint line the first osteotomy line is drawn. Applying the 1° to 1-mm equivalence at the lateral cortex below the initial osteotomy, the second osteotomy line is drawn. The wedge that has been bordered by the two osteotomy lines should be removed. By performing lateral closing wedge osteotomies, the sagittal slope must be assessed repeatedly to avoid significant slope perturbations [5, 8, 12].

8. Surgical technique

We usually start with arthroscopy to perform the debridement of the lateral compartment and to manage the concomitant pathologies regarding the menisci and chondral tissues before starting with the HTO, as recommended [38]. For the correction of genu varum deformity and re-alignment of the lower extremity, medial opening wedge, lateral closing wedge, and dome osteotomy can safely be applied. Our preference is the medial opening wedge osteotomy.

8.1 Medial open wedge osteotomy

In the middle of the line drawn from the tibial tubercule to medial border of tibia, a 3–5 cm longitudinal skin incision is made carefully by beginning 1–2 cm inferior to the medial joint line and continuing caudally to the pes anserinus. After dividing the sartorial fascia, we usually distract the tendons of pes anserinus distally, but an inverted L-shaped flap can also be elevated. After subperiosteal dissection and sufficient exposure of the proximal-medial tibia and the joint line, the superficial medial collateral ligament (sMCL) fibers are elevated from their medial tibial attachment sides; otherwise, if the attachment of sMCL is left intact on the medial tibia, pressures of the medial compartment may inevitably increase as a result of the tensioning of sMCL fibers during the distraction phase of the osteotomy [1, 8]. Proximal to the tibial tubercule, patellar tendon should be identified and protected from the possible damage that might be caused by the blade of the saw by placing a broad retractor anteriorly. It is of high importance to conduct careful subperiosteal dissections in order to protect and secure the posterior neurovascular structures.

After the subperiosteal dissection and exposure of the entire proximal-medial portion of the tibia, a guide wire is inserted, starting proximal to the tibial tubercule and aiming toward the tip of the fibular head with an anteromedial to posterolateral trajectory. After the insertion of the first guide wire, it is optional to place another wire posteriorly to determine the osteotomy's sagittal angle that can influence the amount of the sagittal slope. If a reduction of the posterior tibial slope is desired, the posterior guide wire should be placed more superiorly resulting in a flatter cut. If a rise of the sagittal slope is desired, then the posterior guidewire should be placed more inferiorly.

An oscillating saw is used to make the first cut of the osteotomy on the anteromedial cortex.

This cut is advanced with osteotomes until to a distance of 1–1.5 cm to the lateral cortex of the tibia, in order not to cause any fracture on the tibial plateau. In addition to that, it is also recommended, that the vertical distance from the tip of the osteotome to the lateral tibial plateau should be 1.25 times of the horizontal distance to the lateral tibial cortex, to minimize the risk of any fracture on the lateral tibial plateau. Hereby, the osteotomy is ended, followed by the opening of the osteotomized bone and very gentle and careful application of valgus force on the tibia. Osteotomy side is opened sequentially with calibrated wedges. As a result of that, a new mechanical axis has been reconstructed (**Figure 4**). The new mechanical axis is confirmed by either placing a cord of electrocautery or a long alignment rod from the center of the hip to the center of the ankle and confirming its distance from the knee joint under image intensifier. It was also suggested to add a concomitant tibial tuberosity osteotomy, if more than 12.5 mm correction is required, in order to avoid the potentially adverse effects of patella baja and increased pressure in patellofemoral compartment [8, 39].

The advantages of the medial open wedge osteotomy can be summarized as:

- the ability to provide biplanar correction and biplanar alignment (coronal and sagittal),
- no limb shortening,
- no bone loss,
- no need for fibular osteotomy,

- use of a single cut with no need to detach the muscles,
- little risk of peroneal nerve injury,
- ability to adjust the amount of correction during surgery,
- easier conversion to arthroplasty.

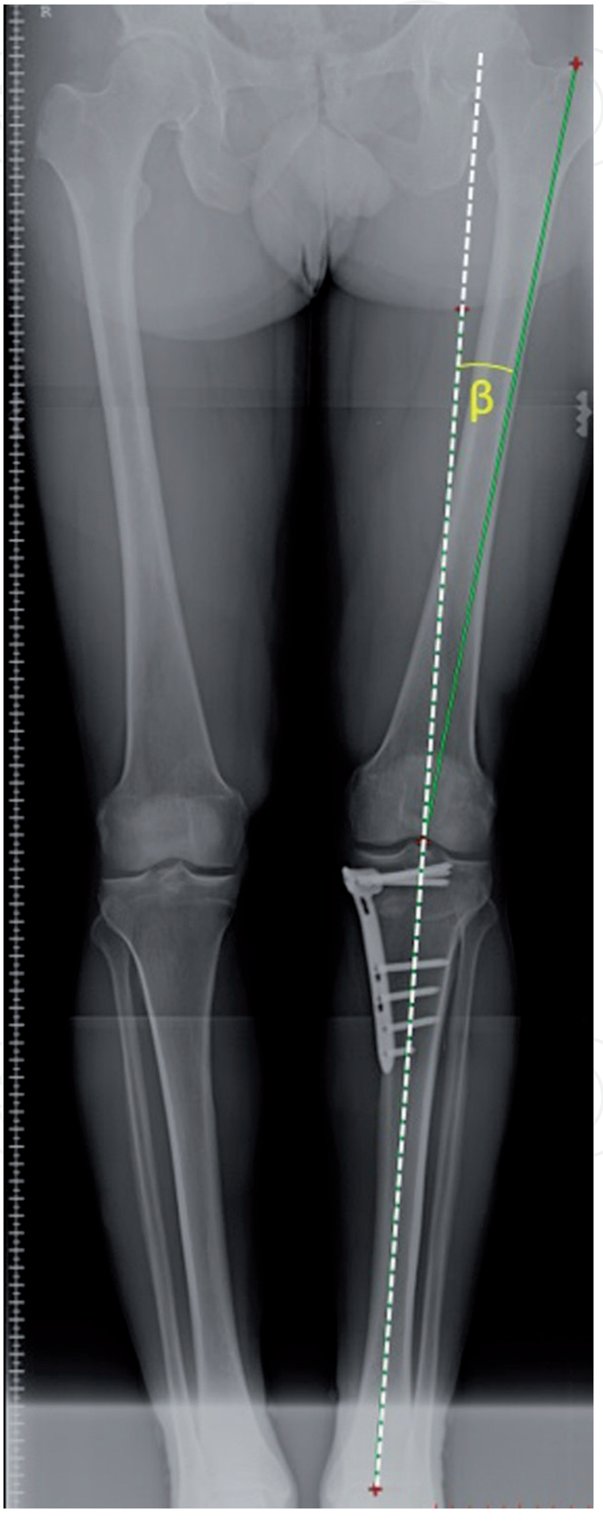

Figure 4.
Post-operative weight-bearing orthoroentgenogram of a patient after MOWHTO. β (7° in this case) is the angle formed by the anatomical axis of femur and the weight-bearing axis (white dashed line) or the mechanical and anatomical axes of tibia, where all three axes are overlapping each other in the tibia.

The disadvantages of the medial open wedge osteotomy can be summarized as:

- the need for bone graft,
- the risk of delayed union or non-union.

8.1.1 Fixation of the medial open wedge osteotomy

Plate fixation was reported to be biomechanically superior as compared to external fixation [40, 41]. Plates without spacer wedges were shown to have higher rates of failure compared to those with wedges [11, 41]. Plate fixators (i.e., The TomoFix plate) are manufactured with the principles of the locking compression plate (LCP) concept; meanwhile offering the advantage of a rigid fixation, and providing early weight-bearing, and early start of motion while the normal pre-operative posterior tibial slope is maintained [13, 14, 42]. TomoFix plates (Synthes, West Chester, PA) and Puddu plates (Arthrex, Naples, FL) were detected to provide adequate biomechanical stability, whereas in case of lateral cortex fracture, TomoFix plates were detected to provide adequate stability without the need of any additional lateral fixation [8, 42]. The biomechanics of three spacer plates with different length was studied, while two were with locking bolts, and one was the TomoFix plate, which was shown to be superior at single load-to-failure and cyclical load-to-failure tests and also possessed the maximum residual stability after failure of the lateral cortex, in addition to least motion at the osteotomy gap [43–45].

8.1.2 Bone healing after the medial open wedge osteotomy

After medial open wedge HTO procedure, healing was shown to start from the lateral hinge and advancing toward the medial aspect, while 3 months after the procedure, callus formation, and ossification was visible [8, 11, 13]. In our clinical practice, 6 months post-operatively more than 80% of the gap is filled with newly formed bone (**Figure 5**), and more than 80% of patients X-ray and CT scan, a consolidation is visible at the end of the first post-operative year.

8.1.3 Spacers and autografts for the medial open wedge osteotomy

To enhance stability and accelerate the healing, we like many other surgeons prefer to fill the gap of osteotomy with grafts or bone substitutes. Post-operative alignment and clinical outcome were reported to be comparable between beta-tricalcium phosphate (TCP) and hydroxyapatite (HAp), but TCP was noted to possess a significant superiority regarding osteoconductivity and bioabsorbability after 18 months [46]. After the TomoFix plate removal, it was observed, that TCP was completely absorbed and the newly forming bone was completely remodeled and incorporated into osteotomized tibia [47].

Autogenous iliac bone graft as the bone filler is widely used at the end of the HTO procedure. It is also considered as a reliable bone filler in patients who are at risk of non-/delayed union such as smokers, obese patients, and those with [48]. Results with autograft were reported to be superior with lower rates of total complications as compared to allograft and bone substitutes such as the calcium-phosphate ceramic spacer [49].

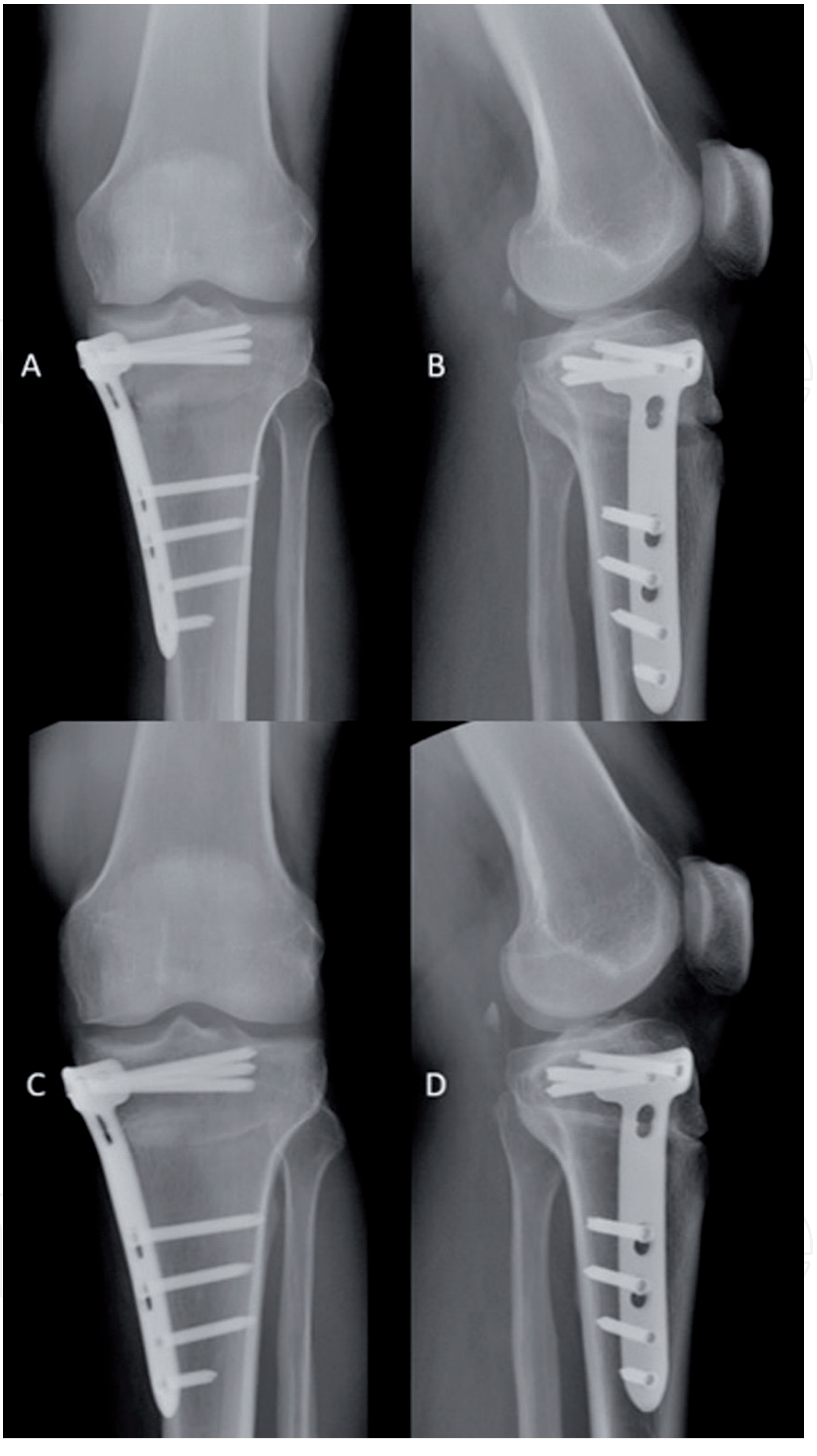

Figure 5.
Anteroposterior and lateral X-rays of the patient after 6 weeks (A and B) and 6 months (C and D) post-operatively.

8.2 Lateral closing wedge osteotomy

Lateral closing wedge osteotomy (LCWO) starts with an inverted L-shaped incision directed anterolaterally, while the vertical part is placed on the lateral edge of the tibial tubercule and the horizontal part is placed 1–1.5 cm distally to lateral knee joint line. This osteotomy requires peroneal nerve exposure and dissection, which is found on the anatomical area located the 2–3 cm distally to fibular proximal styloid process and crossing the neck of the fibula. The nerve should be carefully dissected and protected. After the dissection and protection of the peroneal nerve, the anterior compartment muscles are elevated subperiosteally from the anterolateral aspect of tibia while the incision is advanced distally. Patellar tendon should be protected while placing a retractor between the tendon and the anterior tibia. Following this

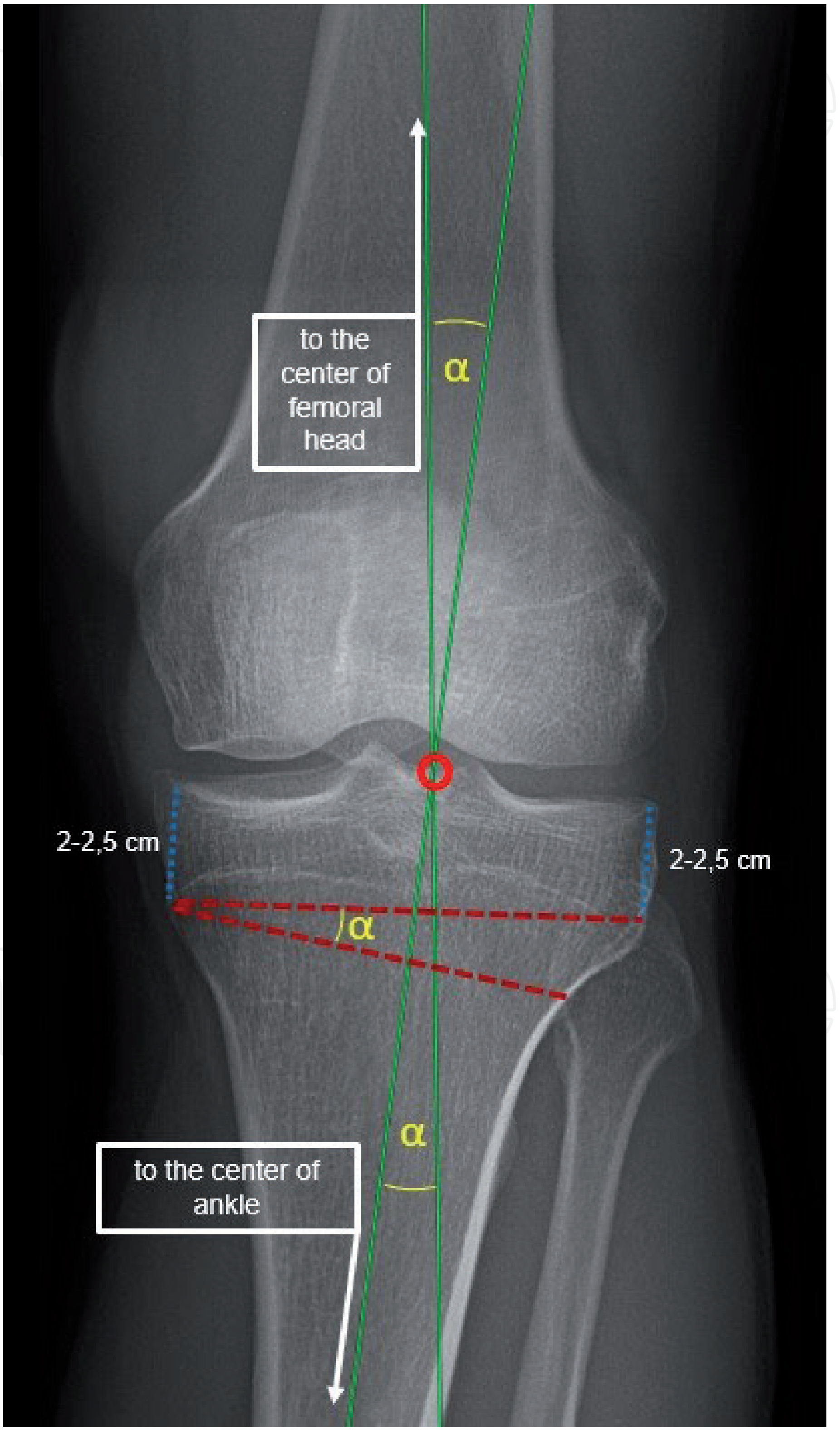

Figure 6.
Pre-operative planning for LCWHTO. α, the correction angle, is the angle formed by the mechanical axes of femur and tibia that are aimed to be provided post-operatively. The osteotomy lines are drawn as red dashed lines.

step, the tibiofibular joint can be disrupted by using an osteotome, combined with the resection of the medial one-third of fibula or applying a fibular shaft osteotomy placed 10 cm distally to the fibular head. After that, we usually identify the joint by using two needles and placing the osteotomy guide parallel to the needles aiming 2–2.5 cm distal to the joint line. Following this step, the osteotomy guide is secured to the bone by using two smooth pins, over which the plate is also placed with high precision to the bone while directing it exactly parallel to the posterior slope of the tibial. Before starting to perform with the osteotomy by using an oscillating saw and osteotomes, posterior neurovascular structures, and patellar tendon should be ensured to be protected by the retractors. It is important to end the tip of the osteotome with a distance of 1 cm from the medial tibial cortex and 2–2.5 cm distal to the knee joint line (**Figure 6**). With the help of the osteotomy guide, the required amount of bone can be resected. This step is followed by the application of the plate over the previously placed pins that are replaced with screws. By using a large reduction clamp, the osteotomy is closed and compressed, followed by the insertion of the remaining screws.

8.3 Dome osteotomy

A dome osteotomy is usually indicated when a correction more than 20° are needed. The osteotomy is performed by applying an inverted U-shaped (dome shaped) osteotomy proximal to tibial tubercule. Especially in cases with accompanying patellofemoral disease, by staying proximal to tibial tubercule, distal tibia is shifted anteriorly, yielding to anterior translation of the tibial tubercule, which maintains the patellar height. After the placement of a jig, anteroposterior drill holes are applied in a half barrel shaped configuration while staying proximal to tibial tubercule. During dome osteotomy a partial resection of the fibular shaft might be necessary. Before starting with the osteotomy, the amount of correction should be certainly indicated on the jig and marked with Steinmann pins located in the proximal and distal fragments. Removal of the jig is followed by careful osteotomizing of the posterior cortex, while the pre-determined amount of correction is achieved by anteriorization of the distal fragment together with the tibial tubercule. Dome osteotomy is usually fixed by using an external fixator. Increased operative time, patient discomfort caused by the external fixator, possible risks of pin tract infections, need for frequent follow-up visits for the fine-tuning of external fixator or assessment of the wound side are the disadvantages of dome osteotomy. In our clinical practice, we do not apply the dome osteotomy frequently as a result of the aforementioned disadvantages, while we spare this procedure for patients requiring high degrees of bony correction.

9. Survival rates of high tibial osteotomy

A good surgical technique combined with rigid fixation together with meticulous patient selection and appropriate post-operative rehabilitation protocols are keys to long-term survival of HTO. Koshino et al. reported 93.2% as the 10-year survival rate for closed wedge osteotomy, related to some post operation factors including, valgus anatomical angle of 10°, no flexion contracture and concomitant patellofemoral decompression procedure if indicated [50]. In patients who underwent medial open wedge high tibial osteotomy a 10-year delay of arthroplasty in 63% of 73 patients [51], and in 85% of 203 patients was shown [52].

In a study of 54 patients with osteoarthritis limited to medial compartment, 24% rate of conversion to arthroplasty was reported after a median of 16.5 years with either medial opening or lateral closing wedge HTO, while no significant difference regarding the functional scores and survival rates was found between the two techniques [53].

It was reported, that authors showed that the lateral closing wedge osteotomy was related to higher number of conversion to total joint replacement, whereas the medial opening wedge HTO was related to higher incidence of complications [54].

Results of HTO were noted to be good within the first 10 years following the surgery; whereas, a worsening of the results was also shown after 15 years [55, 56].

10. Complications

HTO's complication rate was reported between 7 and 55%. It should be remembered that HTO requires a long learning curve leading to decreased rates of complication [1, 7, 8].

With more experience and over the course of years, rates of complications were decreased to 8–15% [1].

It is a fact that medial opening wedge HTO became more popular that the other techniques, because of the successful outcomes. Complications including hardware failure, hardware irritation (up to 40%), loss of correction, non-union, lateral tibial plateau fractures, medial collateral ligament injuries were reported for opening wedge HTO [1, 8, 57]. In addition to that, lateral cortex violation was reports as an important factor for fixation failure, resulting in a minimum 4° of loss of correction in the final follow-up as compared to immediate post-operative X-rays [49]. In a study comprising 100 consecutive MOWHTO patients with an average follow-up of 4 years, allograft combined with plasma-rich platelets and/or DBM was associated with the risk of non-union [58]. Severe adverse events were reported to be seen more common as a result of HTO in patients with diabetes, active smoking, displaced lateral hinge fractures, and patients with no compliance [59].

11. High tibial osteotomy combined with concurrent cartilage procedures

HTO with and without articular cartilage procedures or meniscus allograft transplantation was evaluated in a systematic review assessed and concluded that HTO combined with cartilage procedures led to excellent short-term and mid-term survival and good clinical outcomes, while deterioration was detected after 10 years [60]. Another study of 43 patients with HTO and ACI showed long-term, improved cartilage survival, and a decreased rate of revision in patients with mild varus deformity (<5°) of knee joint [61]. HTO was intended to preserve the joint and chondral surfaces as much as possible to delay the time interval until total knee arthroplasty. In order to be successful and preserve the joint as much as possible, we also prefer to apply concurrent cartilage procedure to delay the TKA as much as possible.

12. Results of high tibial osteotomy

La Prade et al. reported about the modified Cincinnati Knee Scores (CKS) in patients younger than 55 years old who underwent HTO for medial OA and varus deformity in a single surgeon study from 2000 to 2007. They had strict inclusion and exclusion criteria which excluded patients undergoing additional procedures or treatments. Each patient was applied an offloading brace preoperatively. If the patient did not get symptom relief, they were not offered a HTO. Forty-seven patients were available for follow-up. The CKS improved from 42.9 to 65.1 ($P < 0.0001$). Function subscore improved from 24.2 to 34.2 ($P < 0.001$). Functional score improved significantly at 6 weeks, 1 and 2 years [62].

Howells et al. reviewed 164 consecutive patients that underwent lateral closing wedge HTO between 2000 and 2002. Among them, 100 patients met the inclusion criteria and had a follow-up duration of 5–10 years post-operatively. Data were collected prospectively; however, the study reviewed the data retrospectively. To assess outcome WOMAC and KSS were used. At 5 years, 87% of survival rate was reported with the remainder undergoing TKA. This rate dropped to 79% after 10 at 10 years. It was detected that those requiring revision to TKA had a significantly lower WOMAC score (47 vs. 65, $P < 0.001$), were older (54 years old vs. 49, $P = 0.006$) and had a higher BMI (30.2 vs. 27.9, $P = 0.005$). They concluded that a patient less than 55 years old, with a BMI less than 30 and a pre-operative WOMAC score of >45, were positive predictors regarding failure. The authors underlined the importance of using of pre- operative functional scores to use in the decision-making process [63].

Conflict of interest

The authors declare no conflict of interest.

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