Revisiting High Tibial Osteotomy: Fifty Years of Experience with the Opening-Wedge Technique

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Revisiting High Tibial Osteotomy: Fifty Years of Experience with the Opening-Wedge Technique

By A. Poignard, MD, C.H. Flouzat Lachaniette, MD, Julien Amzallag, MD, and P. Hernigou, MD

Introduction
Since the first description by Debye of medial opening-wedge high tibial osteotomy proximal to the tibial tuberosity in 1951 and with the publication of our results in the English-language literature in 1987, our orthopaedic department has performed this osteotomy in 3756 patients over a period of more than fifty years. Although the opening-wedge osteotomy is not new, the advantages of the opening-wedge as compared with a closing-wedge technique have been discussed only recently, particularly in the English-language literature. The aim of the present report is to describe (1) the key steps in the surgical technique, (2) the determination of the size of the wedge, (3) the improvements in the technique during the past twenty years, (4) the specific problem of posterior slope and patella baja, and (5) the technique of concomitant total knee arthroplasty and opening-wedge tibial osteotomy to avoid the need for soft-tissue release in knees with severe varus deformity.

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No funds were received in support of this study.

Key Steps in the Surgical Technique

Initial Exposure
A longitudinal incision is made from the medial border of the patellar tendon distally along the medial aspect of the tibia for 10 cm. The insertions of the sartorius, gracilis, and semitendinosus muscles are divided, and the tendons are separated from bone as described previously. The pes anserinus is incised longitudinally, 0.5 cm medial to its attachment to the tibia; if only moderate valgus is required, the incision can be incomplete. The distal portion of the superficial medial collateral ligament is exposed and is separated from bone proximally as far as the level of the osteotomy, which should be started at least 3.5 cm distal to the medial joint line and directed laterally and proximally toward the tip of the fibula. The posterior compartment is opened at the level of the osteotomy and the posterior surface is cleared, with the periosteal elevator being directed toward the proximal end of the fibula.

The Osteotomy Line
The osteotomy line begins from 3 to 4 cm distal to the medial joint line, passing above the insertion of the patellar tendon to the tibial tubercle. A pin is inserted and is directed toward the lateral border of the tibia at the level of the proximal tibiofibular joint. In patients with a large varus deformity, the osteotomy line is placed at the level of the proximal tibiofibular joint (Fig. 1).

The Osteotomy Is Performed on the Distal Side of a Pin
The osteotomy line is slightly oblique from distal to proximal, and the osteotomy is performed with a chisel on the distal side of the pin to avoid any extension of the osteotomy toward the lateral tibial plateau. The fibula and the tibiofibular joint need not be disturbed. Maximum attention is given to keep the lateral cortex intact to allow hinging at this

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As the cut is completed with osteotomes, the lateral part of the cortex of the lateral tibial plateau is left intact.

The Opening Should Be Medial and Posterior
The bone at the site of the osteotomy is wedged open. The portion of the tibia distal to the osteotomy is then pushed into valgus while the large osteotome maintains the proximal end of the tibia in place. The surgeon avoids flexion at the site of the osteotomy. The opening must be greater at the posterior part of the osteotomy than at the anterior part in order to avoid increasing the posterior slope and patella baja (Fig. 2).

The Size of the Wedge Can Be Tested
The osteotomy gap is distracted and is evaluated with fluoroscopy. Next, a single wedge is placed to keep the wedge area open (Fig. 3-A). This correction can be checked during surgery by calculating the angle between the anatomical axis of the tibia and a line perpendicular to the tibial plateau. The same measurement can be done on the lateral radiograph to ensure that flexion is not present at the osteotomy site. The trial wedge is then exchanged for the final wedge, which is usually a bone substitute (Figs. 3-B and 3-C).

Positioning of the Wedge and Internal Fixation Are Important
The wedge is inserted in the opened osteotomy site medially and posteriorly to avoid relative shortening of the patellar tendon and an increase of the posterior slope of the tibia. A buttress plate is then applied to the anterior part of the medial aspect of the tibia to hold the proximal end of the tibia and the tibial shaft (Fig. 4). The wound is closed by repairing the tendons and the superficial medial collateral ligament.

Determination of the Size of the Wedge
The Hip-Knee-Ankle Angle
A preoperative standing radiograph showing both lower extremities from the hip to the ankle is used to determine the size of the wedge of bone substitute that is needed to produce the correction. First, the lines that determine the preoperative hip-knee-ankle angle are drawn. Usually, for patients with osteoarthritis, the postoperative hip-knee-ankle angle should overcorrect the preoperative angular deformity. The size of the wedge varies with the change of the opening-wedge angle during the osteotomy and the width of the tibia at the site of the osteotomy.

The Graphic Method
On the full-length anteroposterior radiograph, a line is drawn at the osteotomy site. Then a new tibial line, representing the
future mechanical axis of the limb after the osteotomy, is drawn. The angle between this new tibial line and the preoperative tibial line defines the amount of correction needed to produce the desired hip-knee-ankle angle and to restore the mechanical axis of the limb. Next, a tracing of the portion of the tibia that lies distal to the site of the osteotomy is made and is superimposed on the radiograph as previously reported so that the axis of this tracing lies exactly on the previously drawn new tibial line on the radiograph.

The Table Method
This method allows the surgeon to modify the angle of correction by determining the size of the wedge. The size of the wedge varies with the change of the angle during the osteotomy and the width of the tibia at the osteotomy site, and this angle (Beta) is the angle of correction. W is the width of the tibia at the site of the osteotomy and can be determined on the preoperative radiograph or during surgery. For example, if the planned correction is 16° and the width of the tibia at the

Figs. 3-A, 3-B, and 3-C After the osteotomy gap is distracted under fluoroscopy, a trial wedge provided with the specific ancillary instrumentation is used to determine the wedge size needed. Fig. 3-A The trial wedge serves as a distractor to keep the osteotomy site open. Fig. 3-B In most patients, the anteroposterior dimension of the tibia at the site of osteotomy is large enough to allow implantation of the definitive bone substitute while the trial device is still implanted (side by side), as shown. Fig. 3-C The calcium phosphate ceramic DUOWEDGE (Kasios) is designed to be used as a wedge for tibial osteotomies. DUOWEDGE is a synthetic bone substitute. It is a macroporous bioceramic, made of hydroxyapatite and betatricalcium phosphate. The trial wedge can be removed after implantation of the bone substitute.

Fig. 4 The wedge is inserted medially and posteriorly, and the plate is anterior to the wedge.
The wedge size is planned before surgery depending on the preoperative varus deformity. Normal mechanical alignment of the limb is a hip-knee-ankle angle of $180^\circ$. A varus deformity is indicated by a hip-knee-ankle angle of $<180^\circ$, and a valgus deformity is indicated by a hip-knee-ankle angle of $>180^\circ$. The angle correction during the osteotomy is the difference between the planned postoperative hip-knee-ankle angle chosen by the surgeon and the preoperative deformity. Usually, for patients with osteoarthritis, the postoperative hip-knee-ankle angle should be $\geq 180^\circ$.

The wedge size depends on the angle of correction and on tibial width at the site of the osteotomy. $A = \text{angle of correction}$, and $W = \text{width of the tibia at the osteotomy site}$.}

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Improvements in the Technique During the Past Twenty Years

Replacing the Iliac Crest Wedge with a Beta-Tricalcium Phosphate ($\beta$-TCP) Wedge

Autogenous iliac crest has been the gold standard because of its structural characteristics, osteoconductive and osteoinductive potential, and high rate of osteotomy union, although potential complications and late donor-site pain have been reported\(^1\). The use of a bone-substitute wedge eliminates these problems\(^2\). To allow immediate full weight-bearing, we now use the DUOWEDGE porous beta-tricalcium phosphate ($\beta$-TCP) wedge (KASIOS, Launaguet, France). The advantage of low-porosity $\beta$-TCP is its high initial strength, allowing for immediate postoperative weight-bearing.

DUOWEDGE is a unique tibial osteotomy wedge featuring two portions with different porosities: a solid highly resistant portion (resistance to compression, 80 MPa) fits into the cortical area, where the maximum load-bearing zone is located, while a porous portion improves graft incorporation (Fig. 3-B). This wedge is fabricated from biphasic porous ceramic (60% hydroxyapatite $\text{Ca}_{10}[\text{PO}_4]_6[\text{OH}]_2$ and 40% tricalcium phosphate $\text{Ca}_3[\text{PO}_4]_2$) that is manufactured and controlled by Kasios.

Rigid Internal Fixation with Locking Screws and Plate

In our previous long-term (ten to thirteen-year) follow-up study\(^3\), all patients with a varus deformity who needed a revision still had a varus deformity one year after the initial osteotomy. This varus deformity was related to a fracture of the lateral cortex. A fracture of the lateral cortex substantially reduces the stability of the fixation at the site of the opening-wedge osteotomy, and a lateral fixation with a staple is recommended when this fracture occurs. One of the advantages of

Fig. 5

Fig. 6-A, 6-B, and 6-C Severe proximal tibial varus deformity remains a challenging problem during total knee arthroplasty.
locking screw and plate osteosynthesis is that, when a fracture of the lateral cortex occurs, additional lateral fixation is not necessary. We use the Block and Break locking plate (LIMMED, Nesles-la-Valée, France) (see Appendix), which is a new approach to locking screw and plate osteosynthesis. The plate, contoured to the anatomical position of the proximal part of the tibia, is made of steel and can be contoured during surgery if necessary. We use cortical screws for both proximal and distal holes. The innovative locking sleeve, constricting ring, and special screws in Block and Break locking systems ensure an exceptional resistance to shear stress at the screw-plate junction, ensuring solid fixation regardless of bone quality. The Block and Break system will withstand a maximum of 1200 kg

As shown on this standing anteroposterior radiograph, a technique that combines opening-wedge tibial osteotomy and total knee arthroplasty in the same operation allows for the achievement of good realignment without excessive soft-tissue release.

The articular deformity (angle A) is represented by the angle between the two tangents to the femoral condyles and the tibial plateau; the articular deformity will be corrected by the arthroplasty. The extra-articular (constitutional or acquired) part of the deformity is represented by the complementary angle of the angle enclosed by the tibial mechanical axis and the straight-line tangent to the tibial plateau (angle B).
of shear stress at the screw-plate junction and allows immediate full weight-bearing.

**The Specific Problems of Posterior Slope and Patella Baja**

A change in posterior tibial slope may occur when a medial opening-wedge osteotomy is performed. Usually, the surgeon should avoid increasing the posterior slope in knees with osteoarthritis. A possible reason for increased posterior slope in the opening-wedge technique might be a relatively anterior approach to the proximal part of the tibia. Because of concerns about muscle and vessel injury, surgeons often do not clear the soft tissues well posteriorly and cannot perform a proper osteotomy of the posterolateral cortex. To avoid patella baja, the height of the osteotomy should always be greater at the posteromedial cortex than at the tibial tuberosity.

**Combined Total Knee Arthroplasty and Opening-Wedge Tibial Osteotomy**

Total knee arthroplasty in patients with knee osteoarthritis and severe varus deformity (>15°) remains a challenging procedure (Fig. 6-A). Total knee arthroplasty requires a major release of the medial collateral ligament to achieve good ligament balancing. A technique that combines opening-wedge tibial osteotomy and total knee arthroplasty in the same operation allows for the achievement of good realignment without excessive soft-tissue release (Fig. 6-B). Opening proximal tibial osteotomy is performed first, and the total knee arthroplasty is then performed, with stem augmentation, to ensure stability of the construct.

**Preoperative Planning**

Standing anteroposterior radiographs from the hip to the ankle are used to determine the hip-knee-ankle angle. The preoperative deformity has two parts: (1) the articular part, related to wear of cartilage and bone, and (2) the extra-articular part (Fig. 6-C). The articular deformity is represented by the angles between the two tangents to the femoral condyles and the tibial plateau, and this articular deformity will be corrected by total knee arthroplasty. The extra-articular portion of the deformity is the complementary angle of the angle formed by the tibial mechanical axis line and the straight-line tangent to the tibial plateau. This angle is measured on the medial side. The extra-articular deformity must be quantitated preoperatively as it determines the amount of osteotomy correction needed. The first part of the technique is the osteotomy; the second part of the technique is the arthroplasty. In the proximal part of the tibia, only the anterior portion of the joint capsule is released and the pes anserinus is elevated. The superficial medial collateral ligament is divided at its distal insertion, adjacent to the osteotomy site. The insertion of the deep medial collateral ligament is left intact, and the semimembranosus tendon and the posteromedial capsule are preserved. The bone is cut proximal to the level of the tibial tubercle and as far away from the lateral joint surface as possible (at least 30 mm) to leave sufficient bone in the proximal part of the tibia to allow a bone resection of about 10 mm. After the osteotomy, the osteotomy level should be at the level of the proximal portion of the superior tibiofibular joint. The osteotomy site is opened to the required extent and is held open with a bone-substitute wedge. The size of the wedge is determined as previously described in the text. The wedge is inserted in the opened osteotomy site medially and posteriorly to decrease the posterior slope of the tibial plateau. Care must be taken to ensure that the wedge does not protrude into the center of the medullary cavity, where it would interfere with the insertion of the implant stem or of the intramedullary aiming rods used for the insertion of the total knee replacement. Fixation of the osteotomy site is obtained with a plate and screws. Screws may interfere with the insertion of the tibial stem if they protrude into the medullary canal and should never be driven fully home at the initial part of this combined procedure.

**The Arthroplasty**

Once the angular deformity has been corrected by the medial opening-wedge osteotomy, femoral resection for the total knee arthroplasty may proceed. The femoral component is inserted in the usual fashion. For the tibial component, a cut is made with use of a guide with a proximal sensor. The proper amount of advancement of the tibial surface due to the opening osteotomy can be checked while there is a contact point between the tibial surface and the arm of the sensor. A 9-mm resection can be done to remove the same amount of bone on both the medial and lateral sides. One must take care not to remove >9 mm from the lateral tibial plateau, so a maximum amount of bone will be left between the osteotomy and the resection lines. With the angular correction having been achieved with the osteotomy, there is no need for additional soft-tissue releases to balance the total knee arthroplasty. The tibial implant stem will cross the osteotomy site. We use the Ceraver Hermes posterior-stabilized total knee arthroplasty (Ceraver Ostéal, Roissy, France), but one must carefully prepare the insertion site of the tibial tray to avoid fracture of the proximal part of the tibia. Trial insertion of the tibial component is done prior to cementing. Once the trial implants have been removed, the definitive components are inserted and are cemented in place (Fig. 7). Cement that tends to fill the osteotomy gap is carefully removed. The osteotomy defect is filled with bone that was resected during the total knee replacement part of the procedure (Fig. 8).

**Rehabilitation**

The technique that combines opening-wedge tibial osteotomy and total knee arthroplasty in the same operation allows for the achievement of the desired realignment without excessive soft-tissue release (Fig. 6-B). The patient is mobilized early, with limitation of knee motion to 90° of flexion, and is allowed out of bed on the day after surgery. Weight-bearing is allowed with use of two walking aids for the first six weeks. Subsequently, the patient is allowed to return to full weight-bearing and range of motion and to discontinue the use of walking aids.
Discussion

Successful high tibial osteotomy depends on the interrelationships between several variables, with patient selection and surgical technique likely being the most important. Most authors have agreed that middle-aged patients with isolated medial femorotibial degenerative disease, reasonable functional expectations, and a patellofemoral joint without osteoarthritis can benefit from high tibial osteotomy. Many authors have reported that the results of tibial osteotomy are better when the preoperative radiographs do not show changes indicative of advanced osteoarthritis in the medial compartment such as loss of bone, instability because of erosion of bone, laxity of the lateral structures, or subluxation of the tibia. In knees that have ideal correction (a hip-knee-ankle angle ranging from 183° to 186°), there is no progression of the disease. The increased load on the lateral compartment of these knees does not seem to damage the articular cartilage, and the patellofemoral joint usually remains unchanged. Therefore, proximal tibial osteotomy with ideal correction modifies the natural evolution of knee osteoarthritis for several years in patients with severe varus deformity.

Autogenous iliac crest bone graft has been the gold standard for bone-grafting because of its structural characteristics, its osteoconductive and osteoinductive potential, and its high rate of osseous union. Problems with this bone-grafting procedure are related to later donor site pain and potential complications when the bone graft is obtained. The use of a bone-substitute wedge eliminates these problems yet provides only osteoconductive benefit. As this bone-substitute wedge lacks the osteoinductive properties of autogenous iliac crest bone graft, a longer time to osseous union may occur. The porous portion of this substitute acts as an ideal osteoconductive substitute. The well-established bone-healing process of creeping substitution can proceed across the resorbable part. In combination with the locking plate, full weight-bearing is possible immediately after the operation if pain allows. This is an advantage over previous techniques, for which full load-bearing was possible only after six weeks or longer. The osteotomy sites completely consolidated in all of our cases, and no serious complications occurred.

Finally, the surgeon must be aware of the importance of maintaining the integrity of the lateral hinge at the osteotomy site when performing osteotomies with large corrections. Strict attention to technical details during the operation will serve to minimize the occurrence of hinge fracture. Frequent use of the image intensifier in multiple views during the procedure and a high index of suspicion will assist in making the diagnosis of lateral hinge fracture. Care must be taken to identify this intraoperative complication when it occurs and to act accordingly with the application of supplemental lateral fixation.

The opening-wedge osteotomy has some immediate advantages. Specifically, during the osteotomy, no fibular osteotomy is needed; peroneal nerve palsy is less likely; and there is no instability of the lateral knee ligaments. The technique of rigid internal fixation with a plate and screws has the advantage of avoiding pin-track infection, which occurs frequently in association with external fixator pins in patients managed with opening-wedge osteotomy with use of the hemicallotasis tech-
nique. However, probably the most important advantage of the opening-wedge technique is the preservation of bone stock, leading to an easier operative procedure later if a total knee replacement or a repeat osteotomy is done. A closing-wedge osteotomy reduces the amount of bone stock proximal to the tibial tuberosity; thus, evasion of the patellar mechanism at the time of total knee replacement is difficult and it is usually necessary to perform a lateral retinacular release during the early part of the procedure in order to facilitate the evasion of the patella.

After opening-wedge osteotomy, evasion of the patellar mechanism is easier and the lateral retinacular release is not required as often. One of the criticisms of high tibial osteotomy is that it is associated with a high risk of patella baja, resulting in a difficult conversion to a total knee arthroplasty. With a closing-wedge osteotomy, this may be linked to the fact that, with removal of a wedge of bone, the distance between the tibial tubercle and the joint line is decreased, creating redundancy of the patellar tendon and secondary scarring in the retropatellar fat. With an opening-wedge osteotomy, it is important to put the cement block at the posterior part of the osteotomy site to avoid increasing the distance between the tubercle and the joint line. Patella baja did not develop in any patient in our study.

When total knee arthroplasty is performed following a failed high tibial osteotomy, the postoperative mechanical axis never intersects the center of the tibial component because of the deformed proximal part of the tibia, particularly when the tibia has been resected perpendicular to the tibial shaft axis after a closing-wedge osteotomy. After a closing-wedge osteotomy, the use of a prosthesis that has a tibial component with a central peg may result in impingement of the tip of the peg on the lateral part of the tibial cortex, even though the component appears to be centered on the tibial plateau. This difficulty is due to the abrupt change in the flare of the tibial cortex that is caused by the closing-wedge osteotomy, which also alters the relative position of the medullary canal. Consequently, it may be necessary to shift the tibial component slightly medially so that this impingement will not occur. Sometimes a custom-made component will be needed to accommodate the altered anatomy of the tibia. Following an opening-wedge osteotomy, this problem does not occur because the tibial cut is higher and the risk of impingement of the peg on the lateral tibial cortex is decreased.

Another difference between the two techniques is the ability to more easily determine the level of the native tibial joint after an opening-wedge osteotomy. After a closing-wedge osteotomy, this is not possible because the lateral compartment has been pushed down by the wedge removal and because the medial compartment has already had bone loss at the time of the osteotomy. After an opening-wedge osteotomy, the lateral compartment is kept at a more anatomical level.

Correct rotational alignment between the proximal part of the tibia and the diaphysis is more frequent after the opening-wedge osteotomy. With the opening-wedge osteotomy, there is no fibular osteotomy and a hinge is maintained at the site of the tibial osteotomy. This hinge and the absence of fibular osteotomy avoids rotational malalignment during the osteotomy. In our experience, this malrotation of the proximal part of the tibia is more frequent after closing-wedge osteotomy. As a result, a malrotation causing patellofemoral complications is more frequently observed in patients managed with total knee arthroplasty after closing-wedge osteotomy than after opening-wedge osteotomy.

In conclusion, high tibial osteotomy is a re-emerging technology for the treatment of the refractory pain and disability caused by medial femorotibial degenerative articular disease. The outcomes associated with modern-day total knee replacements are encouraging. However, although they are less frequent than they were in the past, complications and morbidity can occur and the long-term outcome in young patients is unknown. Successful high tibial osteotomy is an effective alternative surgical procedure that makes it possible to delay or avoid a total knee arthroplasty in selected patients. Probably the most important advantage of the opening-wedge technique is the preservation of bone stock and an easier operative procedure when it is later necessary to perform a total knee replacement or a repeat tibial osteotomy in a young patient.

Appendix
A figure showing the locking screw plate osteosynthesis system is available with the electronic version of this article on our web site at jbjs.org (go to the article citation and click on “Supporting Data”).

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References


