

# Inverted V–Shaped High Tibial Osteotomy for Medial Osteoarthritic Knees With Severe Varus Deformity



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**Abstract:** A hemi–closing-wedge and hemi–opening-wedge, inverted V–shaped high tibial osteotomy with local bone graft has been reported to be an effective surgical procedure for medial osteoarthritis of the knee. In this procedure, an inverted V–shaped osteotomy is made and a thin wedged bone block is resected from the lateral side and implanted in the medial opening space created after valgus correction. This procedure can provide sufficient valgus correction of the knee with severe varus deformity more easily than can closing-wedge high tibial osteotomy. The inverted V–shaped osteotomy does not change the posterior tibial slope, the patellar height, or the length of the lower limb at all because the center of tibial alignment correction by the inverted V–shaped osteotomy is located near the center of rotation of angulation of the lower-limb deformity. We recently modified this procedure by performing biplanar osteotomy, developing useful cutting guides, and fixing the tibia with a lateral locking compression plate. The surgical technique is described to enable the reproducible creation of the hemi–closing-wedge and hemi–opening-wedge, inverted V–shaped osteotomy with the locking plate for medial osteoarthritic knees with moderate or severe varus deformity.

**L**ateral closing-wedge (CW) high tibial osteotomy (HTO) was established as an effective treatment for medial osteoarthritis of the knee in the 1970s.<sup>1-4</sup> In the 1990s and 2000s, insufficient valgus correction was shown to be the greatest risk factor that worsens the 10- to 20-year results.<sup>5-8</sup> However, CW HTO was technically difficult and had a high complication

rate.<sup>9</sup> Medial opening-wedge (OW) HTO has been widely performed since Staubli et al.<sup>10</sup> and Lobenhoffer and Agneskirchner<sup>11</sup> reported an improved OW procedure in 2003. This procedure includes biplanar osteotomy, an incomplete fracture technique for valgus correction, and fixation with a locking plate system (TomoFix; DePuy Synthes, West Chester, PA). This advancement has enabled early weight bearing after HTO. Recently, favorable short-term results have been reported.<sup>12-16</sup> However, several disadvantages of OW HTO have been pointed out.<sup>17-21</sup> First, it is technically difficult to obtain sufficient valgus correction ( $>15^\circ$ ) without any surgical problems in the knee with severe varus deformity. Second, the posterior tibial slope angle of the tibial plateau increases after surgery. Third, the patellar height decreases after surgery. Fourth, the length of the lower limb increases after surgery. Therefore, an alternative procedure without these disadvantages should be developed for osteoarthritic (OA) knees with moderate or severe varus deformity.

In 2006 we reported the 10- to 15-year follow-up results of the originally developed inverted V–shaped HTO procedure, which could solve the aforementioned disadvantages of the OW HTO.<sup>22</sup> In this procedure, an inverted V–shaped osteotomy was made by resecting a wedged bone block from the lateral side

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**Table 1.** Indications and Contraindications of Hemi-Closing-Wedge and Hemi-Opening-Wedge, Inverted V-Shaped HTO

Indications	
Symptomatic, isolated medial-compartment OA knees with severe varus deformity, the valgus correction angle of which is calculated to be $\geq 15^\circ$ in the HTO	
Post-traumatic genu varum deformity of the tibia	
Spontaneous osteonecrosis of the medial femoral condyle	
Severe congenital genu varum deformity associated with Blount disease, Turner syndrome, rickets, and so on	
Contraindications	
Inflammatory arthritis	
Lateral and/or severe patellofemoral osteoarthritis	
Flexion contracture $>20^\circ$	
$<90^\circ$ of knee flexion	
Relative contraindications	
Tobacco use	
Obesity with body mass index $>30$	
Age $>80$ yr	

HTO, high tibial osteotomy; OA, osteoarthritic.

and implanting the resected bone block in the medial opening space created after valgus correction. The tibia was then fixed with an external fixator, applying a compression force. Thus, this procedure was classified as a hemi-CW and hemi-OW osteotomy with local bone graft. This procedure could provide sufficient valgus correction of the knee with severe varus deformity more easily than could CW HTO procedures, and the long-term results were significantly better than those of conventional CW HTO.<sup>22</sup> Mechanically, this inverted V-shaped osteotomy does not change the posterior tibial slope angle of the tibial plateau, the patellar height, or the length of the lower limb at all because the center of tibial alignment correction (hinge point) of the inverted V-shaped HTO is located approximately at the center of rotation of angulation of the lower-limb deformity.<sup>23</sup> However, this procedure had a few disadvantages. First, it was technically difficult for surgeons to perform, so sufficient experience was needed to perform a precise inverted V-shaped osteotomy. Second, a long period was needed before weight bearing on the operated limb was allowed, that is, more than 10 weeks. To solve these disadvantages, we recently modified this procedure by performing biplanar osteotomy with specially developed, precise cutting guides and fixing the tibia with a lateral locking compression plate (TomoFix Lateral High Tibia Plate; DePuy Synthes). This inverted V-shaped HTO procedure enabled weight bearing after surgery as early as after OW HTO.

The purpose of this surgical technique description was to detail the stepwise method to enable the reproducible creation of the hemi-CW and hemi-OW, inverted V-shaped HTO with a lateral locking compression plate for medial OA knees with moderate or severe varus deformity.

## Surgical Technique

### Indications and Contraindications

The indication for this HTO procedure is symptomatic, isolated medial-compartment OA knees with varus deformity, the valgus correction angle of which is calculated to be  $15^\circ$  or more in the HTO. Commonly, such knees show moderate or severe varus deformity with OA changes classified as stage 3 or 4 on the Kellgren-Lawrence grading scale.<sup>24</sup> Occasionally, knees with severe varus deformity with OA changes (stage 2) and medial meniscal injury, post-traumatic deformity, and spontaneous osteonecrosis of the medial femoral condyle become candidates. Furthermore, the inverted V-shaped osteotomy can be a useful surgical method to treat severe congenital genu varum deformity associated with Blount disease, Turner syndrome, rickets, and so on. The contraindications are listed in Table 1.

Anteroposterior, lateral, and skyline view knee radiographs; an anteroposterior view weight-bearing knee radiograph; and a full-length lower-limb radiograph are taken. Magnetic resonance imaging is commonly used to diagnose meniscal and cartilage injuries.

### Preoperative Planning

Preoperative planning with an appropriate correction angle of the tibia is made using a standing, full-length lower-limb radiograph. The hip-knee-ankle angle, anatomic femorotibial angle, mechanical lateral-distal femoral angle (mLDFA), and medial-proximal tibial angle (MPTA) are measured to identify the origin of the limb deformity and clarify where the genu varum is formed in the lower limb (Fig 1). Then, the weight-bearing line—a straight line from the center of the femoral head to the center of the talar dome—is drawn. To evaluate the degree of alignment deformity of the knee, the point at which the mechanical axis passes across the tibial plateau is determined, and the percentage of this point on the tibial plateau is calculated, with the medial edge defined as 0% and the lateral edge defined as 100%. For moderately or severely OA knees, which are classified as stage 3 or 4 on the Kellgren-Lawrence grading scale, preoperative planning aims to correct the knee alignment so that the mechanical axis passes through a point between 65% and 70% (the Fujisawa point) on the lateral tibial plateau,<sup>4</sup> because sufficient valgus correction is needed to obtain excellent 10-year results.<sup>5-8</sup> For mildly OA knees with severe varus deformity, however, preoperative planning aims to correct the knee alignment so that the mechanical axis passes through the 62.5% point on the lateral tibial plateau.

Inverted V-shaped osteotomy lines are drawn on the full-length lower-limb radiograph so that the apex point (point P) is located at the center of the tibial

condyle and approximately 3 cm to the joint surface line and the apex angle is approximately  $110^\circ$ . To calculate an appropriate angle of the lateral hemi-wedge resection, a long line (line A) is drawn from the center of the femoral head through the 65% point on the lateral tibial plateau. Another line (line B) is drawn from the apex point (point P) to the center of the talar dome, and the length of line B is measured. Then, an arc (arc C), the center and the radius of which are the apex point (point P) and line B, respectively, is drawn across line A. Another line (line D) is drawn from the apex point (point P) to the crossing point between line A and arc C. Then, the angle ( $\alpha$ ) formed between lines B and D provides the lateral hemi-wedge resection angle, which is identical to the correction angle of the lower-limb alignment. A lateral hemi-wedge resection line is drawn using this angle (Fig 2).

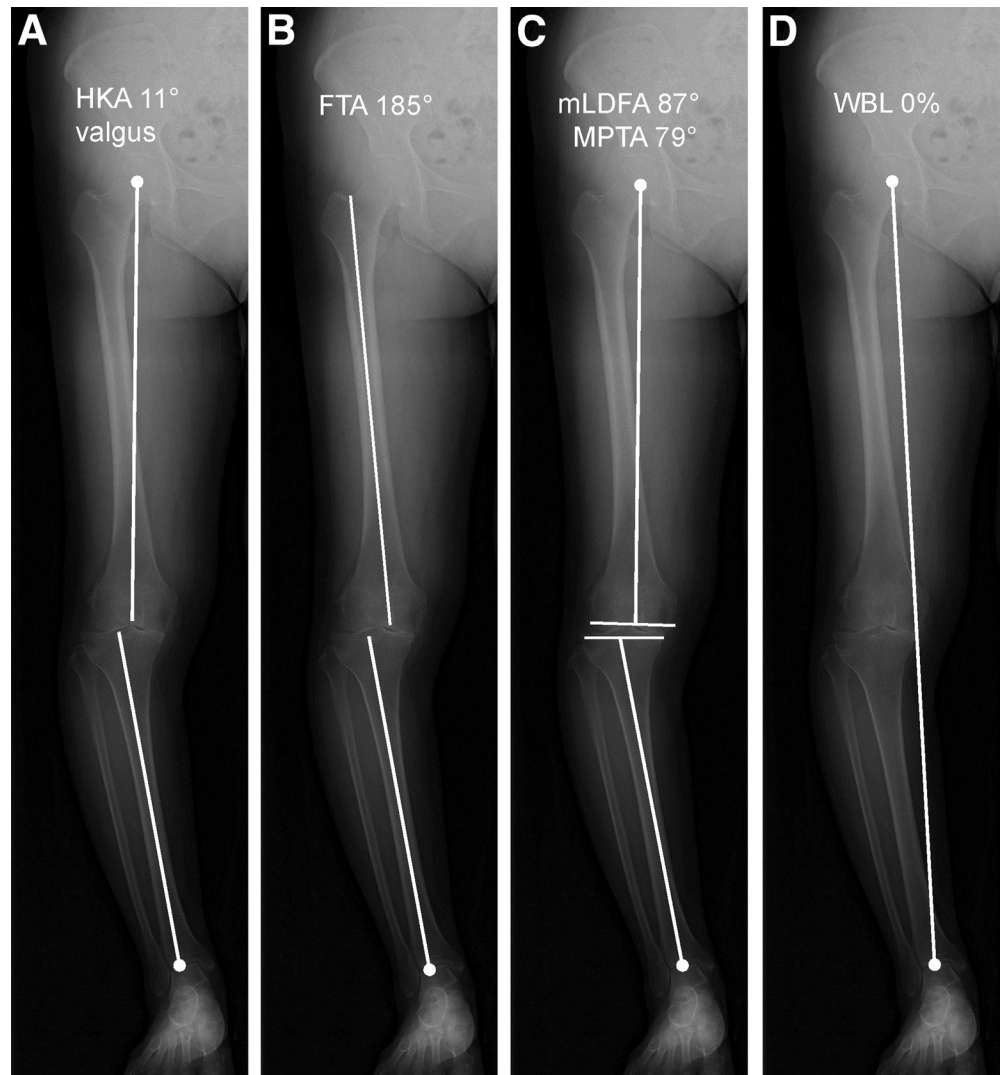
### Patient Positioning

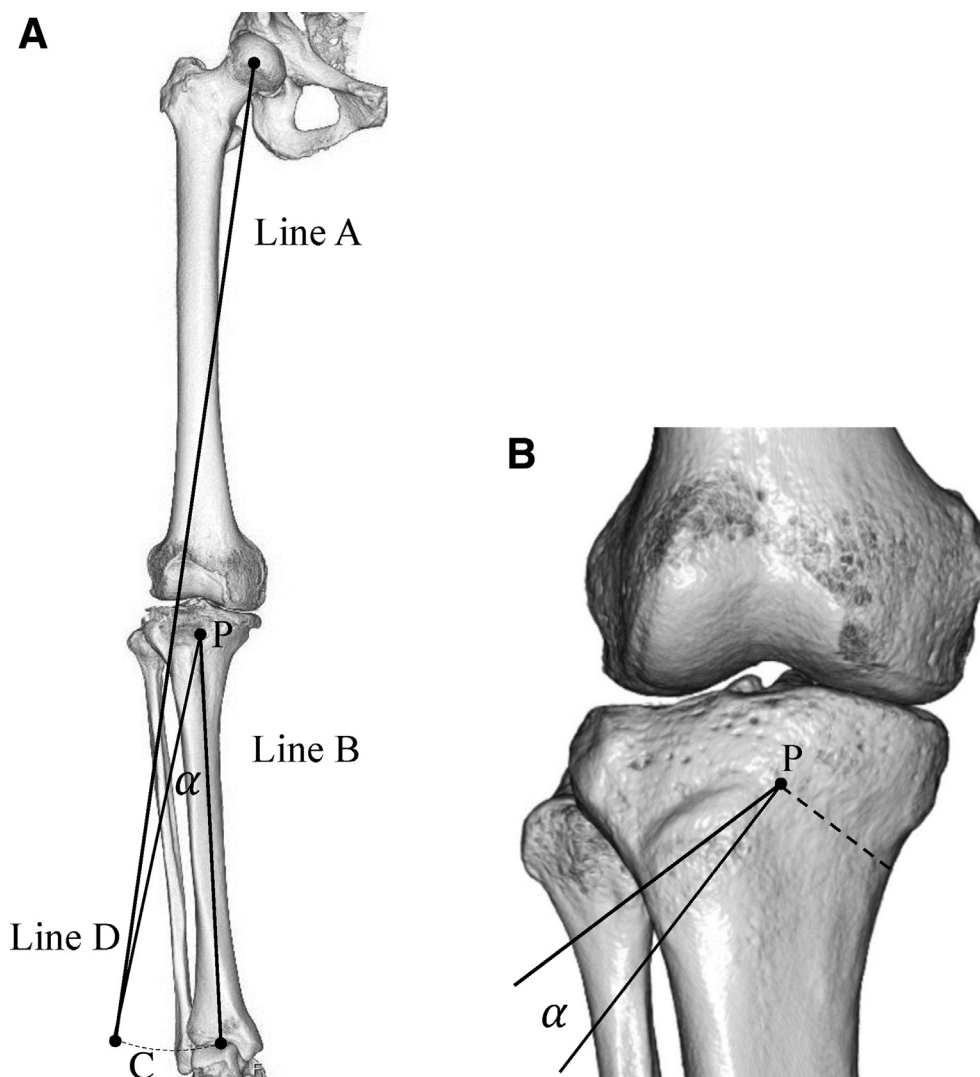
The patient is placed supine on a radiolucent operating table to allow fluoroscopic evaluation from the hip to the ankle. With the patient under general anesthesia, a pneumatic tourniquet is placed high on the thigh of the operative leg. The whole lower limb is sterilized with iodine, and the foot and a distal part of the leg are wrapped with a sterilized stockinet. Then, the body and the opposite lower limb are draped with sterilized waterproof sheets. The surgeon stands at the lateral side of the table, and a C-arm fluoroscope is prepared to come in from the opposite side of the table.

### Diagnostic Arthroscopy and Concomitant Procedures

Diagnostic arthroscopy is performed with standard anterolateral and anteromedial parapatellar portals to confirm the presence of isolated medial-compartment

**Fig 1.** Preoperative planning with an appropriate correction angle of the tibia is made using a standing, full-length right lower-limb anteroposterior radiograph. The hip-knee-ankle angle (HKA) (A), anatomic femorotibial angle (FTA) (B), and mechanical lateral-distal femoral angle (mLDFA) and medial-proximal tibial angle (MPTA) (C) are measured to identify the origin of the limb deformity and clarify where the genu varum is formed in the lower limb. (D) The weight-bearing line (WBL)—a straight line from the center of the femoral head to the center of the talar dome—is drawn. To evaluate the degree of alignment deformity of the knee, the point at which the mechanical axis passes across the tibial plateau is determined, and the percentage of this point on the tibial plateau is calculated, with the medial edge defined as 0% and the lateral edge defined as 100%.





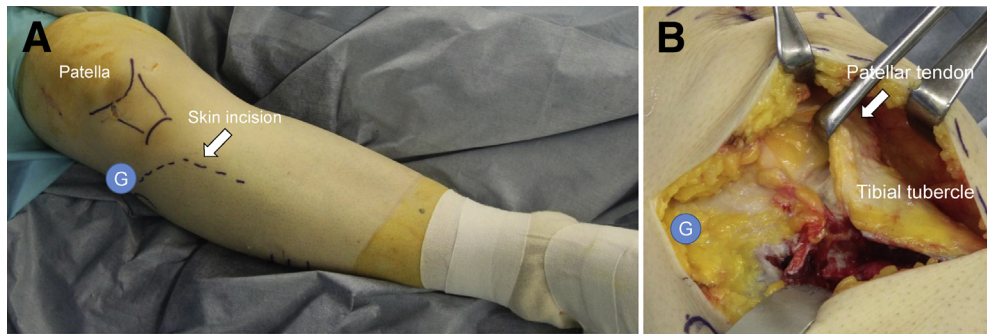
**Fig 2.** (A) Inverted V-shaped osteotomy lines are drawn on the full-length right lower-limb radiograph so that the apex point (point P) is located at the center of the tibial condyle and approximately 3 cm to the joint surface line and the apex angle is approximately  $110^\circ$ . To calculate an appropriate angle of the lateral hemi-wedge resection, a long line (line A) is drawn from the center of the femoral head through the 65% point on the lateral tibial plateau. Then, another line (line B) is drawn from the apex point (point P) to the center of the talar dome, and the length of line B is measured. An arc (arc C), the center and the radius of which are the apex point (point P) and line B, respectively, is drawn across line A. Another line (line D) is drawn from the apex point (point P) to the crossing point between line A and arc C. The angle ( $\alpha$ ) formed between lines B and D provides the lateral hemi-wedge resection angle, which is identical to the correction angle of the lower-limb alignment. (B) A lateral hemi-wedge resection line (dashed line) is drawn using the  $\alpha$  angle.

osteoarthritis. Concomitant procedures can be performed to address medial-compartment chondral or meniscal disease.

### Fibular Osteotomy

After a 4-cm longitudinal incision is made at the posterolateral aspect of the midlower leg ([Video 1](#)), the lateral fascia is exposed. A 4-cm longitudinal incision is made on the posterior one-third portion of the fascia. The peroneal muscle is released anteriorly from the intermuscular septum to approach the fibula. The

periosteum is peeled from the lateral aspect of the fibula using a rasp and then released by inserting an acutely curved elevator posteriorly, both anteriorly and posteriorly between the fibular cortex and the periosteum. Meticulous care is taken to advance the curved elevator along the fibular surface to prevent peroneal nerve and vascular injuries. After the periosteum is circumferentially released from the fibula, 2 short, 2-cm-wide retractors are inserted anteriorly and posteriorly into the medial side of the fibula along the fibular cortex, protecting the neurovascular tissues. An inclined



**Fig 3.** (A) An anterolateral curved skin incision is made on a right knee beginning at the Gerdy tubercle (G). (B) A 2-cm longitudinal incision is made on the lateral patellar retinaculum followed by the medial patellar retinaculum, along the lateral edge of the patellar tendon, starting from the tendon attachment portion to the tibial tubercle in the proximal direction.

(oblique) osteotomy is made at the central portion of the fibula with a thin, 10-mm-wide oscillating saw. This meticulous technique can completely avoid nerve injury and serious bleeding. No fixation is applied to the fibula. After sufficient irrigation, only the subcutaneous tissue and skin are sutured, leaving a suction drainage at the osteotomy portion of the fibula.

#### Approach to Tibia

An anterolateral curved skin incision is made beginning at the Gerdy tubercle and extending approximately 7 cm anterodistally along the midline of the anterior compartment (Fig 3A). A 2-cm longitudinal incision is made on the lateral patellar retinaculum followed by the medial patellar retinaculum, along the lateral edge of the patellar tendon, starting from the tendon attachment portion to the tibial tubercle in the proximal direction (Fig 3B). The distal 2-cm part of the patellar tendon with the fatty tissue is released from the tibia by inserting a 10-mm-wide curved elevator.

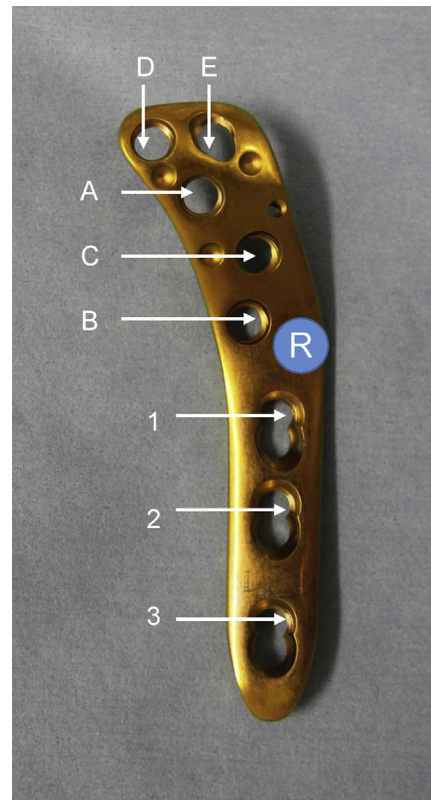
The fascia covering the tibialis anterior muscle is incised along the anterolateral edge of the medial aspect of the tibia from a point just distal to the Gerdy tubercle and extending approximately 7 cm distally. The tibialis anterior muscle attachment is detached subperiosteally from the tibial cortex with a Cobb elevator.

The posterolateral periosteum, with a width of 10 mm, is detached from the tibia through the lateral osteotomy line by inserting an acutely curved elevator. A radiolucent retractor (Olympus Terumo Biomaterials, Tokyo, Japan) is inserted between the tibia and the detached posterior structures to protect the neurovascular structures.

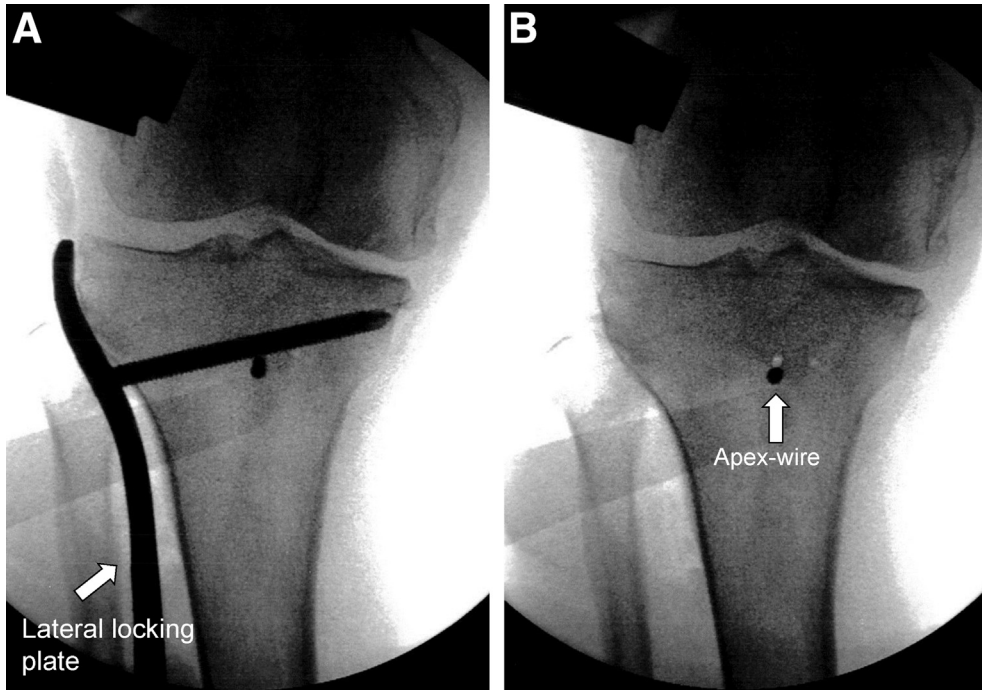
#### Determination of Osteotomy Lines

A lateral locking compression plate (TomoFix Lateral High Tibia Plate) is prepared (Fig 4), and sleeves for drilling are attached at holes E and C in the plate. The surgeon holds the plate, places it on the lateral aspect of the tibia, and determines an appropriate location for the proximal edge of the plate so that hole E is located at a level beneath the subchondral bone of the tibial plateau, observing the positional relation between the plate and the tibia with a C-arm fluoroscope. The location of hole C is then marked on the lateral aspect of the tibia with ink.

proximal edge of the plate so that hole E is located at a level beneath the subchondral bone of the tibial plateau, observing the positional relation between the



**Fig 4.** A lateral locking compression plate (TomoFix Lateral High Tibia Plate) is prepared for the right (R) tibia, and sleeves for drilling are attached at holes E and C in the plate. The surgeon holds the plate, places it on the lateral aspect of the tibia, and determines an appropriate location for the proximal edge of the plate so that hole E is located at a level beneath the subchondral bone of the tibial plateau, observing the positional relation between the plate and the tibia with a C-arm fluoroscope. The location of hole C is then marked on the lateral aspect of the tibia with ink.

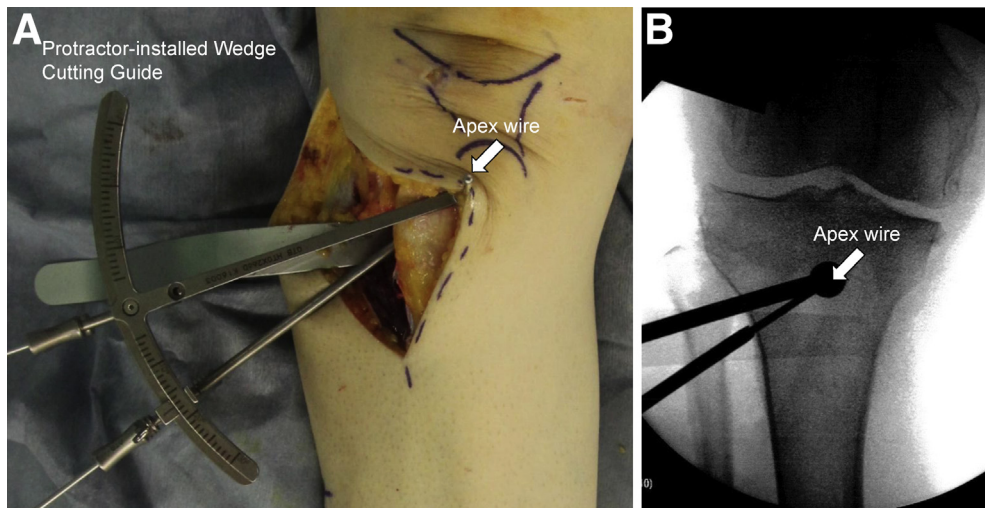


**Fig 5.** (A) Observing the right tibia with a fluoroscope, the surgeon determines the apex point of the inverted V-shaped osteotomy (ie, apex wire) using a lateral locking plate, which is located at the center of the tibial condyle width and approximately 3 cm distal to the joint surface line. (B) The apex point is located approximately at the point where the medial edge of the patellar tendon is attached to the tibial tubercle. Under fluoroscopic control, a Kirschner wire is inserted at this point in the anteroposterior direction.

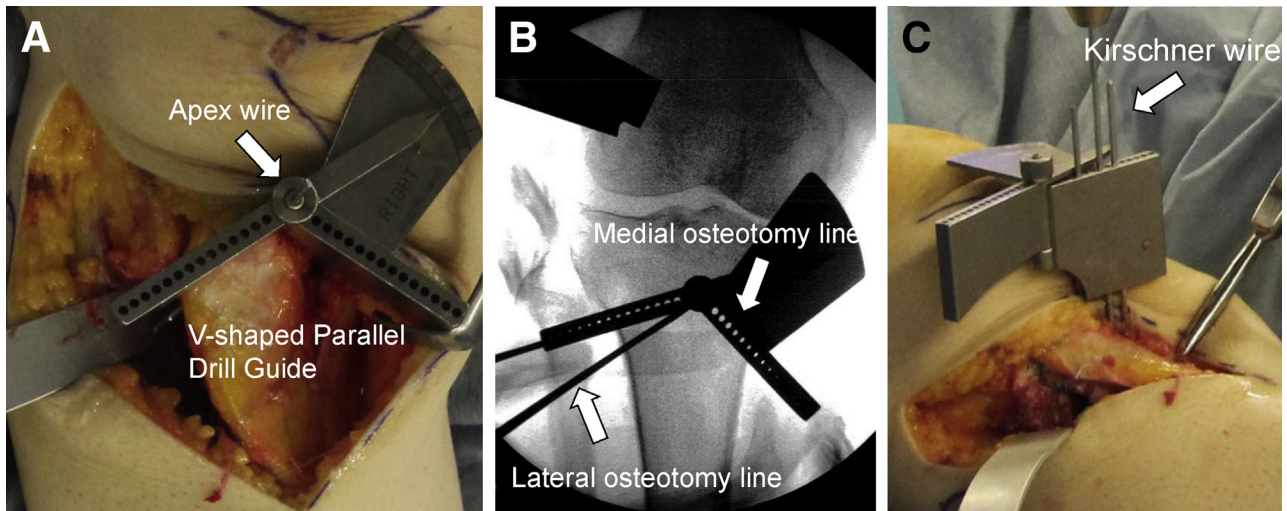
plate and the tibia with a C-arm fluoroscope. The location of hole C is then marked on the lateral aspect of the tibia with ink.

Observing the tibia with a C-arm fluoroscope, the surgeon determines the apex point of the inverted V-shaped osteotomy (defined as the “apex wire”), which is located at the center of the tibial condyle width and approximately 3 cm distal to the joint

surface line (Fig 5). In our experience, the apex point is located approximately at the point where the medial edge of the patellar tendon is attached to the tibial tubercle. Under fluoroscopy control, a Kirschner wire (K-wire) is inserted at this point in the anteroposterior direction. Care is taken to avoid penetration of the posterior cortex by the K-wire to prevent neurovascular injury.



**Fig 6.** (A) The protractor-installed Wedge Cutting Guide is attached to the apex wire in the right tibia. (B) With this guide, 2 pairs of Kirschner wires (K-wires) can be inserted into the tibia through the parallel sleeves so that each inserted K-wire precisely reaches the apex wire. Through a pair of sleeves in this guide, the first pair of K-wires is inserted into the tibia toward the apex wire so that the lateral osteotomy line passes through a point 5 mm distal to the marked hole C point. Then, the other pair of sleeves is set distally at the planned angle with the installed protractor, and 2 K-wires are inserted into the tibia at a location more distal to the first pair toward the apex wire.



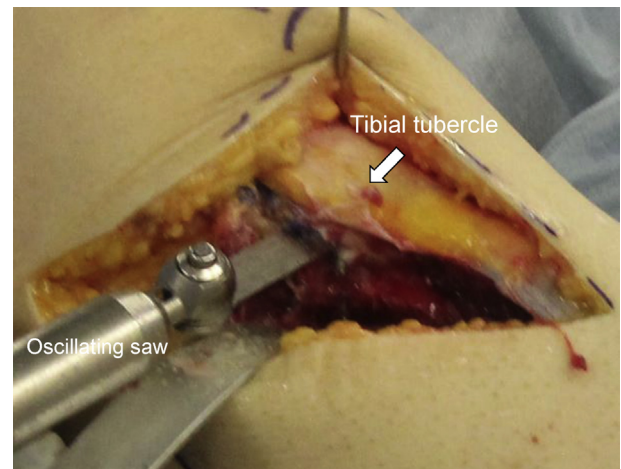
**Fig 7.** (A) A V-shaped Parallel Drill Guide, in which 2-mm-wide tunnels are aligned in parallel with a center-to-center distance of 3 mm, is attached to the apex wire in the right tibia. The apex angle of this V-shaped guide is changeable by the surgeon, measuring with the installed protractor. Commonly, the apex angle of the guide is set at 110°. (B) The lateral side of the V-shaped Parallel Drill Guide is fixed on the lateral osteotomy line. (C) The medial side of this guide is fixed on the medial aspect of the tibia by inserting a 2-mm Kirschner wire into the most medial hole. A total of 7 to 10 parallel holes are drilled into the tibia along the medial osteotomy line using a different 2-mm-thick Kirschner wire.

The protractor-installed Wedge Cutting Guide (Olympus Terumo Biomaterials) is attached to the apex wire (Fig 6). With this guide, 2 pairs of K-wires can be inserted into the tibia through the parallel sleeves so that each inserted K-wire precisely reaches the apex wire. Through a pair of sleeves in this guide, the first pair of K-wires is inserted into the tibia toward the apex wire so that the lateral osteotomy line passes through a point 5 mm distal to the marked hole C point. Then, the other pair of sleeves is set distally at the planned angle with the installed protractor, and 2 K-wires are inserted into the tibia at a location more distal to the first pair toward the apex wire. Each wire is cut short. These 2 pairs of K-wires inserted with a determined angle will be used to guide the lateral hemi-wedge bone resection later.

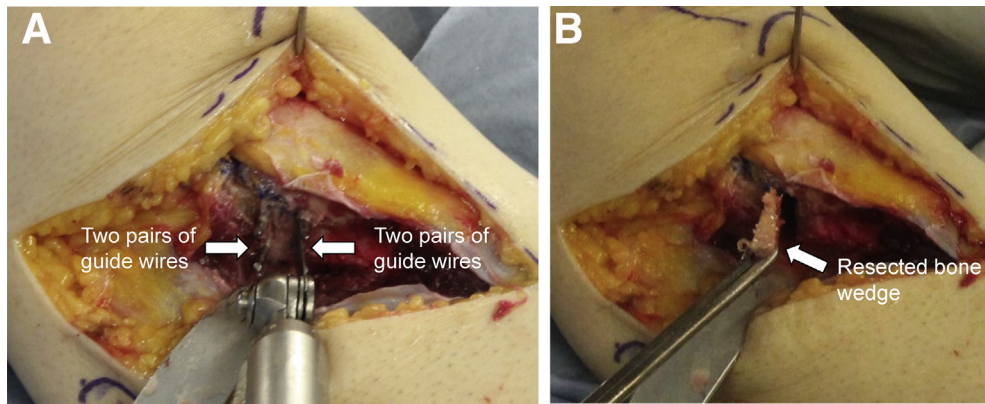
The anteromedial periosteum, with a width of 10 mm, is peeled from the tibia along the medial osteotomy line with a Cobb elevator. Then, the distal portion of the superficial part of the medial collateral ligament and the posteromedial periosteum, with a width of 10 mm, are detached from the tibial cortex along the medial osteotomy line by inserting a curved elevator. A radiolucent retractor is inserted between the tibia and the detached posterior structures to protect the neurovascular structures.

A V-shaped Parallel Drill Guide (Olympus Terumo Biomaterials), in which 2-mm-wide tunnels are aligned in parallel with a center-to-center distance of 3 mm, is attached to the apex wire (Fig 7 A and B). The apex angle of this V-shaped guide is changeable by the surgeon, measuring with the installed protractor.

Commonly, the apex angle of the guide is set at 110°. The lateral side of the V-shaped Parallel Drill Guide is fixed on the lateral osteotomy line. Then, the medial side of this guide is fixed on the medial aspect of the tibia by inserting a 2-mm K-wire into the most medial hole. A total of 7 to 10 parallel holes are drilled into the tibia along the medial osteotomy line using a different 2-mm-thick K-wire (Fig 7C). Drilling is stopped when each K-wire reaches the posterior cortex of the tibia to avoid neurovascular injury. This aligned cortical perforation makes the subsequent osteotomy easy to



**Fig 8.** A coronal ascending osteotomy parallel to the anterior surface of the right tibial tubercle is made with a thin oscillating saw (Hall Instruments), leaving the tibial tubercle intact with a width of 10 mm.



**Fig 9.** (A) A lateral hemi-wedge bone resection is performed along the 2 pairs of guidewires previously inserted in the right tibia. (B) After a radiolucent retractor is inserted between the tibia and the detached posterolateral structures, only the lateral cortex is cut with a thin oscillating saw. The resected bone wedge and the additionally trimmed bone chips are kept moist for grafting of the medial opening space later.

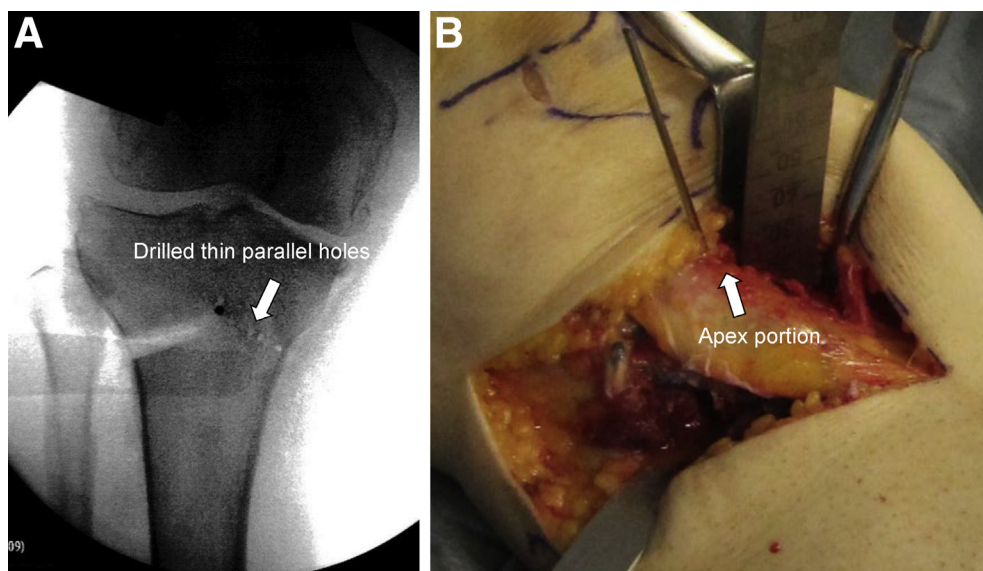
perform with a thin chisel by weakening the strength of the cortical bone.

#### Biplanar Inverted V–Shaped Osteotomy

Biplanar osteotomy is performed in the coronal and sagittal planes. First, a coronal ascending osteotomy parallel to the anterior surface of the tibial tubercle is made with a thin oscillating saw (Hall Instruments; ConMed, Utica, NY), leaving the tibial tubercle intact with a width of 10 mm (Fig 8).

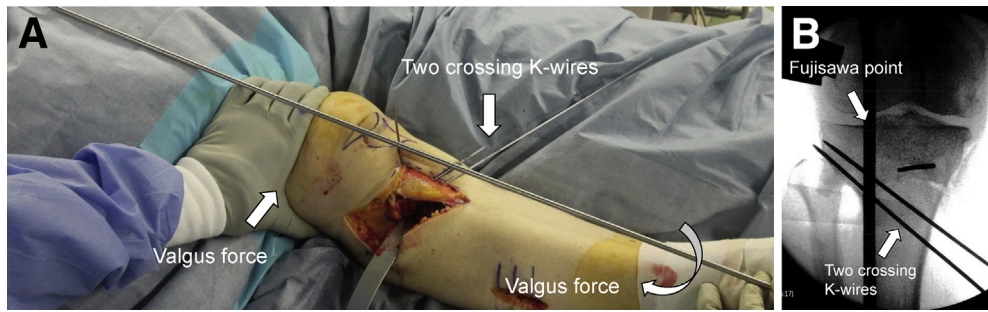
Second, a lateral hemi-wedge bone resection is performed along the 2 pairs of guidewires previously inserted. After a radiolucent retractor is inserted between the tibia and the detached posterolateral structures, only the lateral cortex is cut with a thin oscillating saw (Hall Instruments); then, the posterior

cortex and cancellous bone undergo osteotomy with a thin chisel to avoid heat necrosis of the bony tissue (Fig 9A). The resected bone wedge and the additionally trimmed bone chips are kept moist for grafting of the medial opening space later (Fig 9B). Then, the surgeon observes the created hemi-wedge space and confirms whether the widths of the anterior and posterior spaces are equal. If they are not equal, additional trimming of the bone surface is carefully performed with a thin chisel to obtain complete contact between the proximal and distal surfaces of the post-osteotomy tibia. Complete contact is more easily obtained in this hemi-wedge resection procedure than in the full CW resection procedure because the space after the hemi-wedge bone resection is much narrower.



**Fig 10.** The medial side of the right tibia undergoes osteotomy with a thin chisel along the previously drilled thin parallel holes (A), leaving a 5-mm bony bridge at the apex portion intact (B).





**Fig 11.** (A) The surgeon performs valgus correction of the right tibia by manually applying a valgus force to the knee and confirms that the created lateral hemi-wedge space is completely closed. The assistant surgeon temporarily fixes the proximal and distal parts of the right tibia by inserting 2 crossing Kirschner wires (K-wires) into the tibia. (B) Fluoroscopic evaluation is performed using a long, straight metal rod, which is placed above the centers of the hip and ankle joints. The surgeon confirms that the mechanical axis of the corrected knee passes through the Fujisawa point (65%) on the tibial plateau.<sup>3</sup>

Third, after a radiolucent retractor is inserted between the tibia and the detached posteromedial structures, the medial side of the tibia undergoes osteotomy with a thin chisel along the previously drilled thin parallel holes (Fig 10A), leaving a 5-mm bony bridge at the apex portion intact (Fig 10B). This technique will enable the tibial alignment to be changed by making an incomplete fracture at this portion later.

### Correction of Tibial Alignment

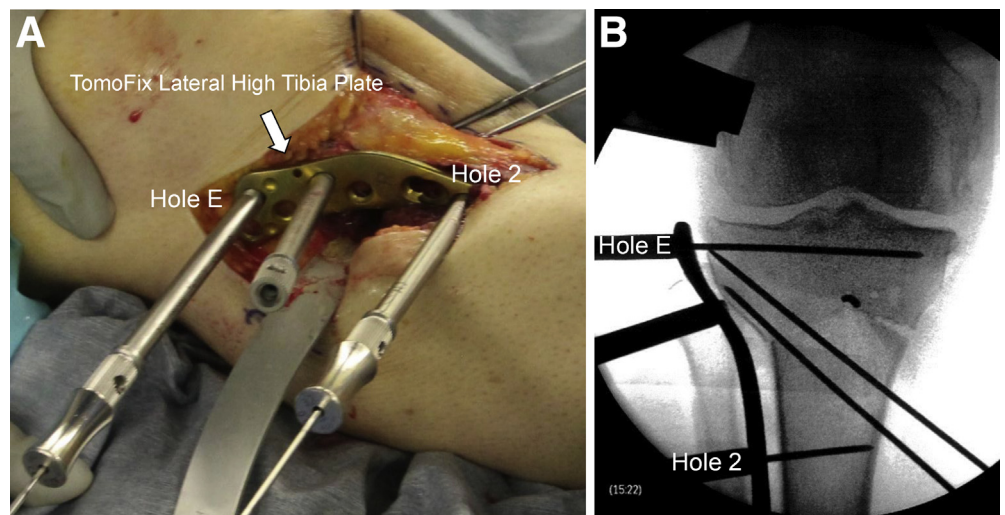
The surgeon performs valgus correction of the tibia by manually applying a valgus force to the knee and confirms that the created lateral hemi-wedge space is completely closed. The assistant surgeon temporarily fixes the proximal and distal parts of the tibia by inserting 2 crossing K-wires into the tibia. Fluoroscopic evaluation is performed with a long, straight metal rod, which is placed above the centers of the hip and ankle joints (Fig 11A). The surgeon confirms that the mechanical axis of the corrected knee passes through

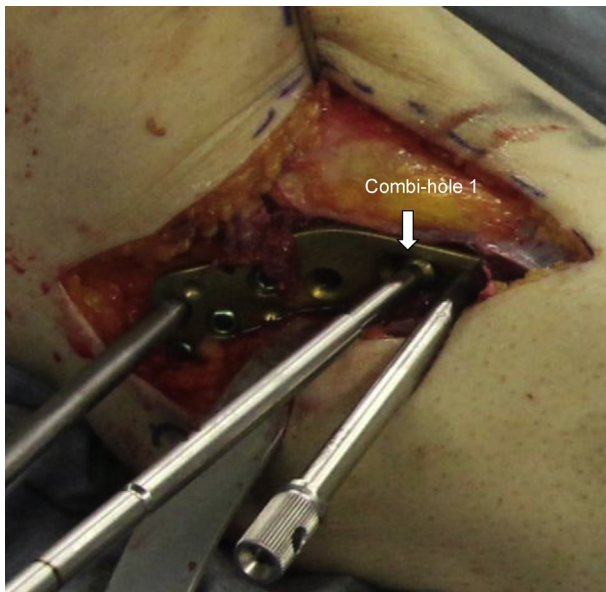
the Fujisawa point (65%) on the tibial plateau (Fig 11B).<sup>3</sup> When the surgeon is satisfied with the degree of alignment correction, the previously resected wedged bone block is grafted to the created medial opening space.

### Fixation With Plate

The TomoFix Lateral High Tibia Plate, on which 4.3-mm Threaded LCP Drill guides (DePuy Synthes) were attached to hole E followed by hole 2, is again placed on the lateral side of the tibia (Fig 12A). With observation of the fluoroscopic image, a 2-mm K-wire is inserted through the 2-mm TomoFix Guide Sleeve attached to hole E into the proximal tibia at a sufficiently proximal level, parallel to the joint line (Fig 12B). Then, a different K-wire is inserted through the sleeve attached to hole 2, after the surgeon confirms that the previously obtained appropriate valgus correction is maintained. These 2 K-wires can temporarily immobilize the plate placed on the lateral side of

**Fig 12.** (A) The TomoFix Lateral High Tibia Plate, on which 4.3-mm Threaded LCP Drill guides are attached to hole E followed by hole 2, is again placed on the lateral side of the right tibia. (B) With observation of the fluoroscopic image, a 2-mm Kirschner wire is inserted through the 2-mm TomoFix Guide Sleeve attached to hole E into the proximal tibia at a sufficiently proximal level, parallel to the joint line.





**Fig 13.** To apply a compression force to the post-osteotomy surface, a bicortical drill hole is created through combination hole 1 (Combi-hole 1) with a 3.2-mm drill sleeve, and a 4.5-mm cortical screw is inserted without applying a compression force on the right tibia.

the alignment-corrected tibia. Then, locking screw holes are drilled through 4.3-mm drill bits attached to holes A, C, and D. The plate is rigidly fixed to the proximal part of the tibia by inserting 5.0-mm locking head screws into these holes. The K-wire inserted through hole E is removed, and a 5.0-mm locking head screw is inserted in the same manner.

To apply a compression force to the post-osteotomy surface, a bicortical drill hole is created through combination hole 1 with a 3.2-mm drill sleeve, and a 4.5-mm cortical screw is inserted without applying a compression force (Fig 13). Then, the K-wire inserted into hole 2 is removed, and the surgeon applies an appropriate compression force to the lateral post-osteotomy surface by turning the screw, carefully



**Fig 15.** Closure is completed with absorbable sutures in layers in a right knee.

observing the osteotomy line after the crossing K-wires are removed.

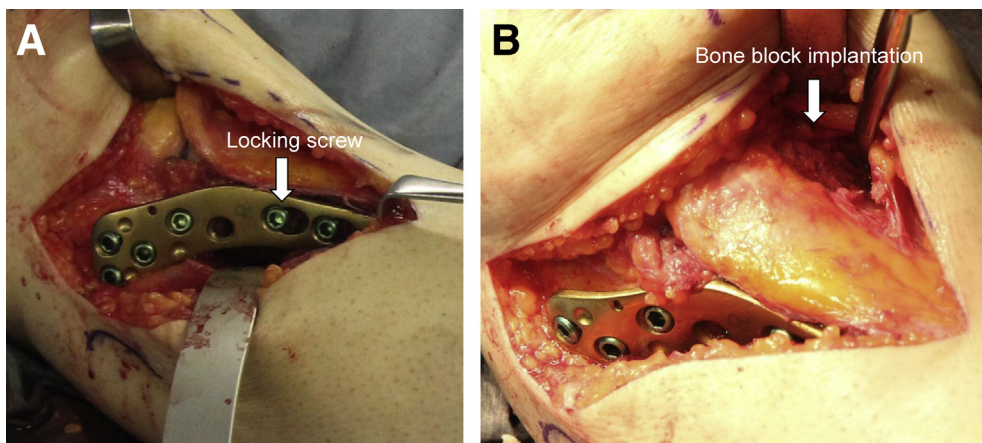
The distal part of the plate is rigidly fixed to the tibia by bicortical insertion of a 5.0-mm locking head screw into hole 2 followed by hole 3 using the drill guides. Then, the cortical screw inserted into combination hole 1 is removed, and a 5.0-mm locking head screw undergoes bicortical insertion into the combination hole in the same manner (Fig 14). Finally, the resected bone block is implanted in the medial opening space created after plate fixation.

### Closure and Dressing

The wound is irrigated with normal saline solution, and meticulous hemostasis is obtained. The medial periosteum is repaired as much as possible with absorbable sutures (Fig 15). The anteroproximal part of the fascia covering the tibialis anterior muscle is tethered with nonabsorbable sutures to fibrous tissue at the lateral edge of the tibial tubercle, leaving the distal part of the transected fascia unrepaired to prevent anterior compartment syndrome. Closure is completed with absorbable sutures in layers (Fig 15). A soft dressing and a cooling device are applied without any knee braces. Preoperative and postoperative radiographs are shown in Figure 16.

### Postoperative Rehabilitation

After the surgical procedure, no brace is applied. Starting on postoperative day 1, a supervised physical therapy program is initiated, with emphasis on



**Fig 14.** (A) The cortical screw inserted into combination hole 1 is removed, and a 5.0-mm locking head screw undergoes bicortical insertion into the combination hole in the same manner in the right tibia. (B) The resected bone block is implanted in the medial opening space created after plate fixation.



**Fig 16.** Preoperative and postoperative plain radiographs in a right knee (R): preoperative anteroposterior (A) and lateral (B) views and postoperative anteroposterior (C) and lateral (D) views.

quadriceps activation. Quadriceps-setting and straight leg-raising exercises are performed 3 to 5 times daily. During the first 2 weeks, passive range of motion is allowed in a range between  $0^{\circ}$  and  $90^{\circ}$  of knee flexion. The patient remains non-weight bearing for 2 weeks. Then, weight bearing is gradually increased based on clinical and radiographic evidence of bone healing. An example of the rehabilitation protocol is shown in Table 2.

## Discussion

Common medial OA knees with severe varus deformity can be treated with the described procedure. Namely, the inverted V-shaped HTO procedure is recommended for knees with severe varus deformity that show an MPTA of less than  $80^{\circ}$  with an almost normal mL DFA ( $85^{\circ}$ - $90^{\circ}$ ). However, we occasionally encounter knees with severe varus deformity with multiple deforming sources, including tibial deformity (abnormal MPTA), femoral deformity (abnormal mL DFA), tibial plateau depression, and joint line convergence in the coronal plane. When marked varus deformity of the femur (mL DFA  $>90^{\circ}$ ) is combined with the tibial deformity, combined femoral and tibial osteotomies are recommended.

The described procedure has several advantages, which are listed in Table 3, compared with OW and CW HTO procedures. Because the center of tibial alignment correction (hinge point) is located approximately at the center of rotation of angulation of the lower-limb deformity, no changes occur in the leg length or the patellar height, even though there is no limitation of

the degree of valgus correction. In addition, deformation of the proximal tibia is minimal after inverted V-shaped HTO. Marti et al.<sup>17</sup> and Brouwer et al.<sup>18</sup> reported that patellar height decreases and the length of the lower limb increases after OW HTO. El-Azab et al.<sup>25</sup> reported that CW HTO leads to an increase in patellar height. Altered patellar height may induce anterior knee pain and result in long-term patellofemoral cartilage degeneration.<sup>26</sup> On the other hand, residual proximal tibial deformity affects the degree of

**Table 2.** Rehabilitation Protocol

Weight bearing
The patient is allowed only touch-down weight bearing at 2 wk.
The patient is allowed half weight bearing at 4 wk.
The patient progresses to full weight bearing as tolerated at 6 wk.
Range of motion
CPM is started in a range between $0^{\circ}$ and $30^{\circ}$ immediately after surgery and is advanced to a range between $0^{\circ}$ and $90^{\circ}$ as tolerated for the first 3 wk. The goal is to perform CPM for 3-4 h/d as able.
The patient progresses to full range of motion from 6-12 wk.
The patient should have full range of motion by 12 wk.
Exercises
The patient may perform heel slides, quadriceps sets, straight-leg raises, and hamstring and calf stretching for the first 6 wk.
Spinning on a stationary bicycle with no resistance is added at 6 wk.
Mini-squats, stationary bicycling with resistance, and swimming are added at 8 wk.
Use of a treadmill with a walking or running program is added at 12 wk.
The patient should progress to activities as tolerated over a period of 3-6 mo postoperatively.

CPM, continuous passive motion.

**Table 3.** Advantages and Limitations of Inverted V–Shaped HTO

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Absolute advantages	
	There is no limitation on the degree of valgus correction.
	The center of tibial alignment correction (hinge point) is located approximately at the center of rotation of angulation of the lower-limb deformity.
	No changes occur in the leg length or the patellar height.
	Minimal deformation of the proximal tibia occurs (more beneficial in future total knee arthroplasty).
	The lateral wedge resection and medial opening space are the smallest among all HTO procedures.
	No vacant space occurs in the tibia owing to grafting of the resected bone block after surgery.
	There are no changes of bone stock in the tibia.
	No artificial materials remain in the tibia after surgery.
	Less damage occurs to the medial collateral ligament.
	A lower magnitude of periosteum release on the posterolateral and posteromedial aspects is required.
Relative advantages compared with conventional CW HTO	
	The inverted V–shaped osteotomy with biplanar osteotomy of the tibial tuberosity increases stability of the post-osteotomy tibia against shear forces after plate fixation, resulting in earlier bone union.
	It is technically easier to perform precise wedge resection from the lateral tibia because the wedge is small enough that the lateral post-osteotomy aspects are perfectly contacted after alignment correction, resulting in earlier bone union.
	An incomplete fracture technique at the apex portion of the inverted V–shaped osteotomy enhances bone union.
Limitations	
	Fibular osteotomy is needed.
	The tibialis anterior muscle is released from the tibia.
	The procedure is technically more demanding than OW HTO.

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CW, closing wedge; HTO, high tibial osteotomy; OW, opening wedge.

difficulty in possible future total knee arthroplasties.<sup>27</sup> Furthermore, the inverted V–shaped HTO procedure, that is, hemi-CW and hemi-OW osteotomy with local bone graft, has some additional advantages. First, the lateral wedge resection space and medial opening space are the smallest among the HTO procedures. Second, there is no vacant space in the tibia owing to grafting of the resected bone block after surgery. Third, bone stock in the tibia does not change after surgery. Fourth, no artificial materials remain in the tibia after surgery. Fifth, the inverted V–shaped HTO procedure damages the medial collateral ligament less. Sixth, this procedure requires a lower magnitude of periosteum release at the posterolateral and posteromedial aspects.

However, the inverted V–shaped HTO procedure has some limitations (Table 3). First, fibular osteotomy is

needed. Second, the tibialis anterior muscle is released from the tibia. Third, this procedure is technically more demanding than OW HTO, although it is less demanding than CW HTO.

Pearls and pitfalls are listed in Table 4. The medial side of the tibia undergoes osteotomy with a thin chisel along the previously drilled thin parallel holes, leaving a 5-mm bony bridge at the apex portion (hinge point) intact. This technique will enable a change in tibial alignment by making an incomplete fracture. Valgus correction of the tibial alignment should be performed slowly by manually applying valgus and compression forces to the knee. It should be left in place for 5 minutes to allow for stress relaxation of the cortices to prevent fracture. Concerning the pitfalls, a lateral approach to the proximal tibia and fibular osteotomy

**Table 4.** Pearls and Pitfalls

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Pearls	
	The medial side of the tibia undergoes osteotomy with a thin chisel along the previously drilled thin parallel holes, leaving a 5-mm bony bridge at the apex portion intact. This technique will enable a change in tibial alignment by making an incomplete fracture.
	The use of a radiolucent retractor to protect the posterior neurovascular structures allows the surgeon to fluoroscopically access the osteotomy without having to remove it.
	Valgus correction of the tibial alignment should be performed slowly by manually applying a valgus force to the knee. It should be left in place for 5 min to allow for stress relaxation of the cortices to prevent fracture.
Pitfalls	
	A lateral approach to the proximal tibia and fibular osteotomy poses an intrinsic risk to the peroneal nerve. A careful approach and protection of the nerve reduce the risk of injury.
	To apply a compression force to the lateral post-osteotomy surface, a cortical compression screw should be inserted through the combination hole of the plate. Then, the surgeon applies an appropriate compression force to the lateral post-osteotomy surface by turning the screw, carefully observing the lateral osteotomy line after the crossing Kirschner wires are removed.
	Consolidation problems may occur with opening-wedge osteotomies. Preserving local biology and filling the gap with bone graft when it is >10 mm minimize the risk of this complication.
	Avoiding smoking and the use of other nicotine products prevents consolidation problems.

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poses an intrinsic risk to the peroneal nerve. A careful approach and protection of the nerve reduce the risk of injury. To apply a compression force to the lateral post-osteotomy surface, a cortical compression screw should be inserted through the combination hole of the plate. Then, the surgeon should apply an appropriate compression force to the lateral post-osteotomy surface by turning the screw, carefully observing the central hinge point and the lateral osteotomy line after the crossing K-wires are removed.

We use lateral plating with the TomoFix plate because lateral plating is biomechanically effective. Patients can start partial weight bearing at 4 weeks after surgery and full weight bearing at 6 weeks. However, the rehabilitation of the OW osteotomy with the locking plate system is faster than with this inverted V-shaped procedure.

The described procedure can provide sufficient valgus correction of knees with severe varus deformity more easily than CW HTO procedures, and the long-term results are significantly better than those of the conventional CW HTO.<sup>22</sup> However, further long-term studies are needed to assess the subjective and objective patient outcomes of inverted V-shaped osteotomy in patients with severe varus malalignment. We recommend our approach to achieve successful bipplanar lower-extremity realignment and encourage further studies by other groups to evaluate our surgical technique.

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