Technical Note

Quantitative Technique to Precisely Fix the Tibia With a Locking Compression Plate at the Preoperatively Planned Correction Angle While Applying High Compression to the Osteotomy Site in Inverted V—Shaped High Tibial Osteotomy

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Abstract: In high tibial osteotomy (HTO) fixed with a locking compression plate (LCP), overcorrection or under-correction of knee alignment frequently occurs because the LCP applies not only proximal displacement but also valgus rotation to the distal tibia. We have developed a quantitative technique to precisely fix the tibia with the LCP at the preoperatively planned correction angle in inverted V—shaped HTO. Preoperatively, simulation of the HTO using the LCP is performed with a radiograph, and the distance of the most proximal locking screw from the articular surface is measured. During surgery, a marker wire is precisely inserted into the proximal tibia at the preoperatively planned position of the most proximal locking screw. By inserting the first screw along this marker wire, the LCP is precisely installed on the proximal tibia at the planned position. Then, a compression screw is inserted into the distal tibia through the LCP. This screw pulls the distal tibia toward the distal part of the LCP while applying proximal displacement and valgus rotation. Thus, the tibia is precisely fixed at the planned correction angle.

Neutral-wedge high tibial osteotomy (HTO) and lateral closed-wedge HTO are useful surgical options for medial knee osteoarthritis (OA).[1-5] In these HTO procedures, a locking compression plate (LCP) is a useful device to securely fix the osteotomized tibia, applying a compression force to the osteotomy site.[2,6] In fixation with the LCP, however, overcorrection of knee alignment frequently occurs compared with the preoperative plan.[2] To eliminate cases with not only overcorrection but also under-correction in these procedures, there is a need to develop a quantitative fixation technique with the LCP that can precisely achieve the preoperatively planned tibial correction after applying a compression force.

The inverted V—shaped (iV) HTO, which is defined as a hemi—lateral closed-wedge and hemi—open-wedge osteotomy, is classified as a neutral-wedge HTO.[2,3,7,8] This procedure has attracted notice as a useful surgical option for medial OA knees with severe varus deformity.[2,7-9] We present a quantitative technique to precisely fix the tibia with the LCP at the preoperatively planned correction angle in iV HTO.

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Technique

Planning

The tibial valgus correction angle is determined using the method of Miniaci et al.[10] based on a full-length standing anteroposterior (AP) radiograph of the right lower extremity (Fig 1).[2,8] Initially, the following 4 points are marked on the radiograph: (1) the center of

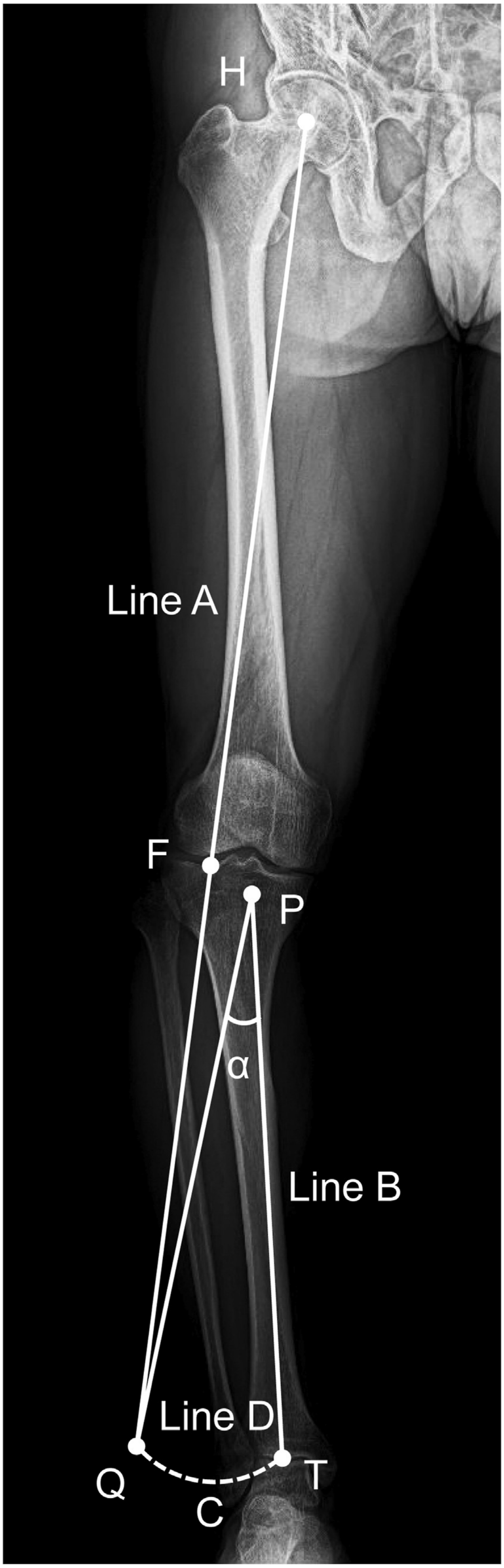

Fig 1. The tibial valgus correction angle is determined using the method of Miniaci et al.[10] based on a full-length standing anteroposterior radiograph of the right lower extremity.[2,8] Initially, the following 4 points are marked on the radiograph: (1) the center of the femoral head (point H), (2) the center of the talar dome (point T), (3) the apex point of the inverted V—shaped osteotomy (point P), and (4) the point on the lateral tibial plateau surface (point F) where the intended postoperative mechanical axis of the lower extremity intersects. Point P is located on an extension of the perpendicular to the joint line from the apex of the medial intercondylar eminence and is placed 20 to 25 mm distal from the joint surface line. We have determined point F to be the point 67% from the medial edge of the tibial plateau in high tibial osteotomy for patients with advanced medial knee osteoarthritis. A straight line is drawn from point H through point F (line A). Then, a line segment is drawn between points P and T (line segment B). Subsequently, an arc centered at point P that has line B as its radius is constructed (arc C). The intersection of line A and arc C is defined as point Q, and a line segment is delineated between points P and Q (line segment D). The angle between line segments B and D is defined as angle α, which represents the correction angle required for the inverted V—shaped high tibial osteotomy.

the femoral head (point H), (2) the center of the talar dome (point T), (3) the apex point of the iV osteotomy (point P), and (4) the point on the lateral tibial plateau surface (point F) where the intended postoperative mechanical axis of the lower extremity intersects. Point P is located on an extension of the perpendicular to the joint line from the apex of the medial intercondylar eminence and is placed 20 to 25 mm distal from the joint surface line. We have determined point F to be the point 67% from the medial edge of the tibial plateau in HTO in patients with advanced medial knee OA. A straight line is drawn from point H through point F (line A) Then, a line segment is drawn between points P and T (line segment B). Subsequently, an arc centered at point P that has line B as its radius is constructed (arc C). The intersection of line A and arc C is defined as point Q, and a line segment is delineated between points P and Q (line segment D). The angle between line segments B and D is defined as angle α, which represents the correction angle required for the iV HTO.

A 2-dimensional simulation of the iV HTO is performed on an AP radiograph of the knee (Fig 2). We use a commercially available LCP (TriS Inverted-V Lateral HTO Plate; Olympus Terumo Biomaterials, Tokyo, Japan) (Fig 3A). A transparent adhesive film (Olympus Terumo Biomaterials) that depicts the AP view of this LCP is prepared and applied on the radiograph (Fig 2B) to conform precisely to the lateral contour of the proximal tibia (Fig 3B). Figure 3B represents the optimal LCP installation to precisely achieve the preoperatively planned correction angle.

Theoretically, if the proximal part of the LCP is accurately installed on the proximal segment of the

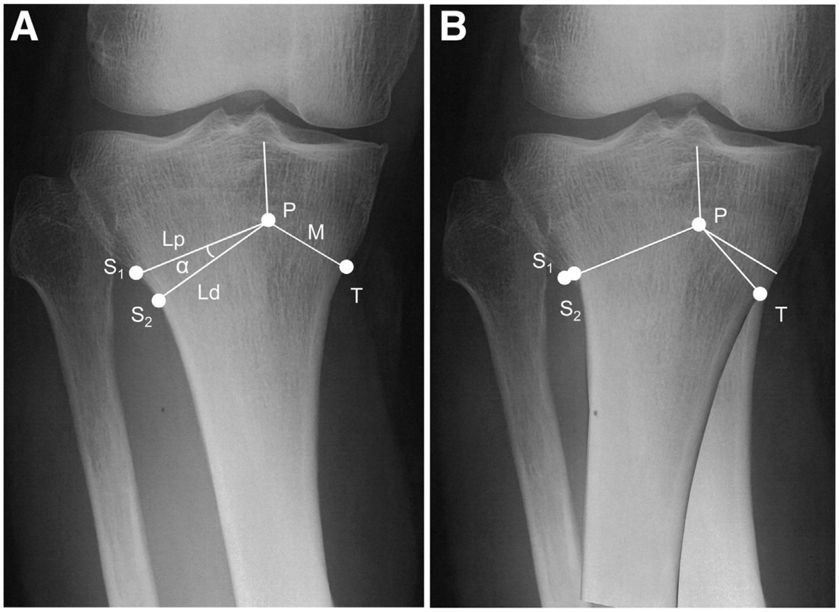

Fig 2. Two-dimensional simulation of inverted V—shaped high tibial osteotomy. (A) On the printed radiograph, point P is located on an extension of the perpendicular to the joint line from the apex of the medial intercondylar eminence of the right proximal tibia and is placed 20 to 25 mm distal from the joint surface line. Point S_1 is marked on the surface of the lateral tibial cortex and 5-mm distal lower margin of the proximal tibiofibular joint. The proximal osteotomy line (line Lp) is delineated, connecting point P with point S_1. Then, the distal osteotomy line (line Ld) is delineated from point P, forming correction angle α with line Lp. The medial osteotomy line (line M) is drawn from point P to the medial cortex (T). Commonly, the apex angle of the inverted V—shaped osteotomy is set at 110°. (B) The tibial segment distal to lines Ld and M is excised from the printed radiograph. This segment is pasted on the remaining radiograph to ensure line Ld aligns completely with line Lp. Then, the distal osteotomy line (line Ld) is delineated from point P to point S_2, forming correction angle α between lines Lp and L_d.

tibia (Fig 3B), the preoperatively planned valgus correction can be precisely and easily achieved by pulling the distal segment of the tibia toward the distal part of the LCP. Obviously, the position of the LCP to the proximal tibial segment is determined by the location of the first locking screw inserted into the proximal segment. Therefore, to accurately insert the first screw into the proximal tibial segment as depicted in Figure 3B, the distance of the insertion point on the lateral cortex from the joint line and the distance of the aiming point on the medial cortex from the joint line are measured on the radiograph (Fig 3B).

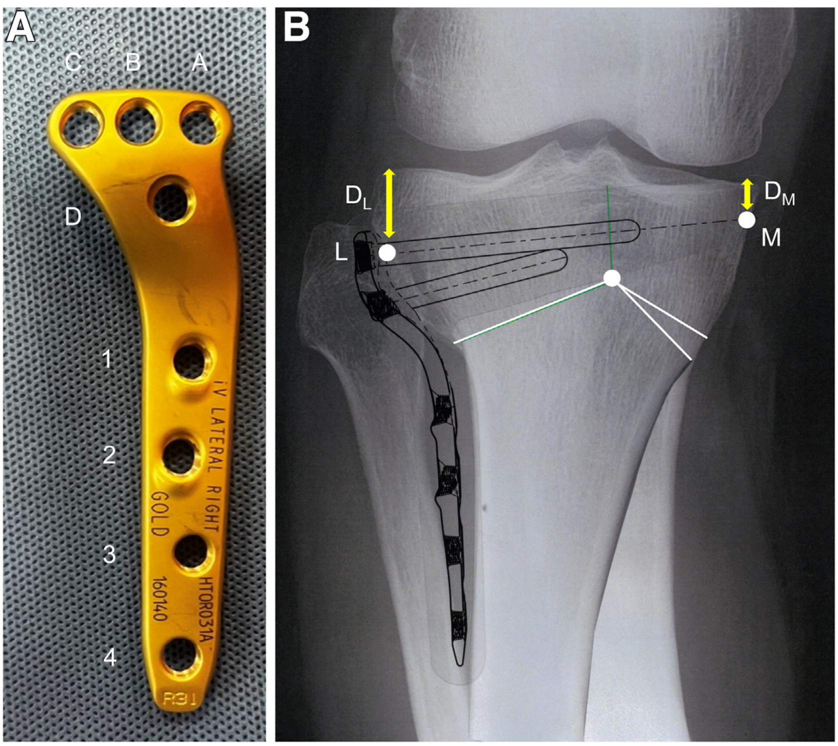

Fig 3. Preoperative preparation of optimal locking compression plate installation. (A) A lateral locking compression plate (TriS Inverted-V Lateral HTO Plate) is prepared for the right tibia. Holes A through D are the proximal locking screw holes; holes 1 and 2, the compression screw holes; and holes 3 and 4, the distal locking screw holes. (B) The anteroposterior image of the plate, which is depicted on a transparent film (Olympus Terumo Biomaterials), is applied on the radiograph (Fig 2B) to conform precisely to the lateral contour of the right proximal tibia. Then, the distance between the proximal screw and the articular surface is measured. The location of this screw in the tibia can be determined by the following 2 points on the tibial cortex: lateral insertion point of the screw (L) and medial aiming point of the screw (M). Points L and M are quantified by their distances from the lateral (D_L) and medial (D_M) joint surfaces, respectively.

Fibular Osteotomy

An acute oblique osteotomy procedure with suture ligation, which was previously reported in detail,[11] is performed to shorten the right fibula because this procedure provides a high union rate (almost 100%) at the fibular osteotomy site with no complications.[9] After a 4-cm longitudinal incision is made at the posterolateral aspect of the mid-lower leg, a 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. The central portion of the fibula is circumferentially isolated from the surrounding tissues using 2 curved retractors. A fibular osteotomy is made at the center point of the shaft on the quasi-frontal plane, which is inclined by 25° to 30° to the long axis of the fibula, using a thin oscillating saw (Micro Sagittal Blade; Hall Instruments—ConMed, Utica, NY). Immediately before the osteotomy is completed, 2 holes are created in the lateral cortices of the 2 fibular fragments using a 2-mm-diameter K-wire. After completion of the osteotomy, a No. 2 polyester thread (Ethibond Excel Suture; Johnson & Johnson Medical, New Brunswick, NJ) is passed through the 2 holes using a suture passer.

Inverted V—Shaped HTO

The details of the iV HTO procedure have been previously reported.[2,8] An approximately 10-cm curved skin incision is made on the anterolateral aspect of the right proximal tibia, extending from the Gerdy tubercle to the anterior aspect of the tibia. A 2-cm longitudinal incision is made for a biplanar osteotomy along the lateral margin of the tibial tuberosity, followed by dissection of the fascia along the anterolateral crest of the tibia. The tibialis anterior muscle is detached from the tibia with a Cobb elevator. The attachment of the interosseous membrane to the tibia, found approximately 1 cm distal to the proximal tibiofibular joint, is incised. The posterolateral periosteum, with a width of 10 mm, is detached from the tibia through the lateral hemi-wedge osteotomy line by inserting an acutely curved elevator. A radiolucent retractor (Olympus Terumo Biomaterials) is inserted between the tibia and the detached posterior structures to protect the neurovascular structures.

Under observation with a C-arm fluoroscope, a K-wire is inserted perpendicular to the anterior surface of the proximal tibia and into the apex of the V-shaped osteotomy, which is located at the center of the tibial condylar width and approximately 25 mm distal to the joint surface line (Fig 4A, Video 1). 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. Care is taken to avoid penetration of the posterior cortex by the K-wire to prevent neurovascular injury.

The Protractor-Installed Wire Insertion Guide (Olympus Terumo Biomaterials), in which the angle of the 2 sleeves is matched to the angle of the planned bone resection, is attached to the apex K-wire (Fig 4B). Then, 2 other K-wires are inserted from the lateral side of the tibia through the sleeves so that each inserted K-wire precisely reaches the apex wire (Fig 4C). A specially designed Parallel Drill Guide (Olympus Terumo Biomaterials), in which 2-mm-wide tunnels are aligned in parallel, is attached to the 2 proximally inserted K-wires (Fig 4D). After multiple drilling applications are completed to create a proximal row of parallel bone holes, this device is removed from the K-wires; then, it is attached to the distally inserted K-wires. A distal row of parallel bone holes is created in the same manner (Fig 4E). After all K-wires are removed from the lateral tibia, the positions of the 2 rows of bone holes in the lateral tibia are clearly confirmed with a fluoroscope (Fig 4F). A wedge osteotomy is made along each row of parallel drill holes using a thin oscillating saw (Hall Instruments—ConMed), followed by a thin chisel (Fig 4G). The resected bone wedge and the additionally trimmed bone chips are kept moist for grafting of the medial opening space later (Fig 4H).

The coronal ascending osteotomy parallel to the anterior surface of the tibial tubercle is performed—except for the apex wire portion—using a thin oscillating saw (Hall Instruments—ConMed), leaving the tibial tubercle intact with a width of 10 mm (Fig 4I). The anteromedial periosteum and a part of the superficial medial collateral ligament are scraped from the tibia just along the medial osteotomy line. A Parallel Drill Guide is attached to the apex K-wire so that the guide is located on the medial osteotomy line (Fig 4J). Commonly, the apex angle of the iV osteotomy is set at 110°. Multiple parallel holes are created in the tibia by inserting a 2-mm-diameter K-wire into parallel sleeves in this guide (Fig 4K). Care is taken to avoid penetration of the posterior cortex by the K-wire to prevent neurovascular injury. The medial side of the osteotomy is performed using a thin chisel along the created parallel holes (Fig 4L).

Prior to valgus correction, a K-wire is inserted from the anteromedial aspect of the distal tibia through the apex of the V-shaped osteotomy to prevent a complete fracture (Fig 5A). The surgeon applies a valgus force to the tibia so that the lateral wedge space is closed (Fig 5B). Temporary fixation is made using another K-wire (Fig 5C).

Fixation Technique With LCP

Step 1. Under fluoroscopy, the lateral screw insertion point (point L) and the medial aiming point (point M)

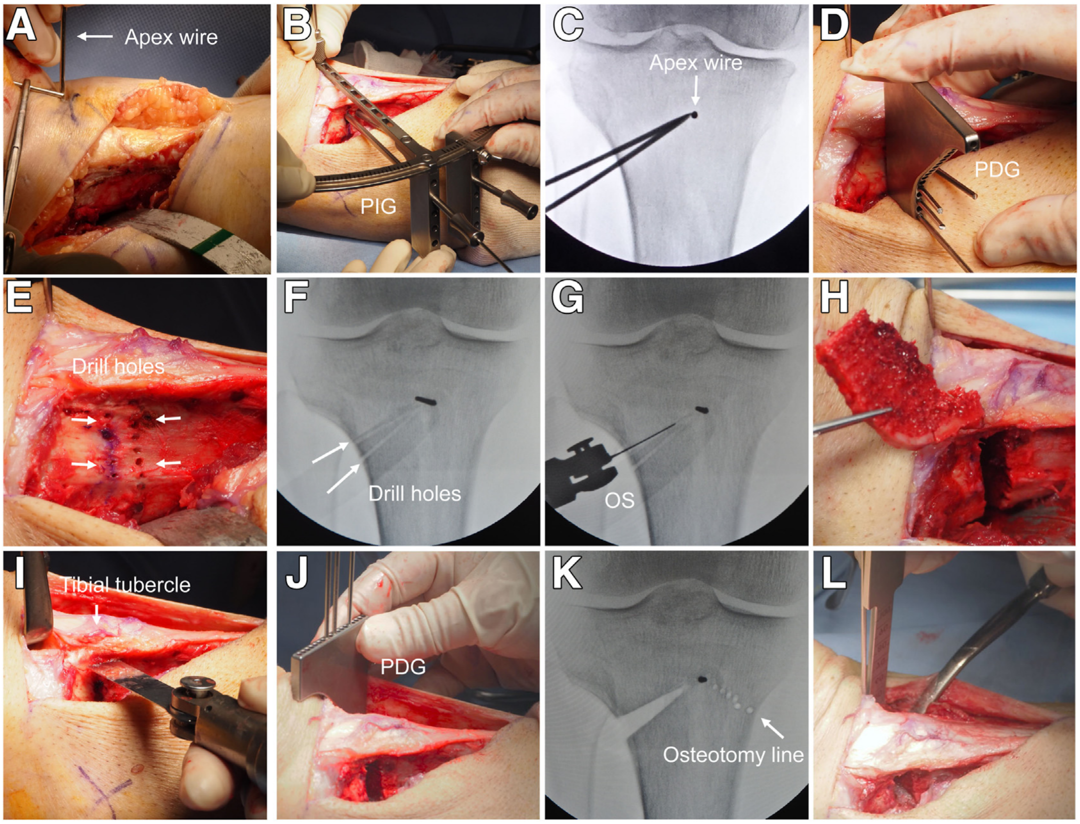

Fig 4. Overview of inverted V—shaped high tibial osteotomy procedure in right tibia. (A) Under observation with a fluoroscope, a K-wire is inserted perpendicularly into the apex of the V-shaped osteotomy, which is located at the center of the tibial condylar width and approximately 25 mm distal to the joint surface line. (B) The Protractor-Installed Wire Insertion Guide (PIG) is attached to the apex K-wire. (C) Two pairs of K-wires are inserted from the lateral side of the proximal tibia through the sleeves. (D) To perform the drill osteotomy, the parallel drill guide (PDG) (Olympus Terumo Biomaterials) is attached to the proximal pair of inserted K-wires. (E, F) Multiple drilling applications are made with a K-wire to create proximal and distal rows of parallel bone holes. (G) A lateral hemi-wedge osteotomy is made along each row of parallel drill holes using a thin oscillating saw (OS) (Hall Instruments—ConMed) and chisel. (H) The resected bone wedge and the additionally trimmed bone chips are kept moist for grafting of the medial opening space later. (I) The coronal ascending osteotomy of the tibial tubercle is carried out using a thin oscillating saw (Hall Instruments—ConMed), leaving the tibial tubercle intact with a width of 10 mm. (J, K) Multiple drilling applications for medial hemi-opening osteotomy are made using the PDG. Commonly, the apex angle of the inverted V—shaped osteotomy is set at 110°. (L) Medial osteotomy is completed along the created multiple parallel holes using a thin chisel.

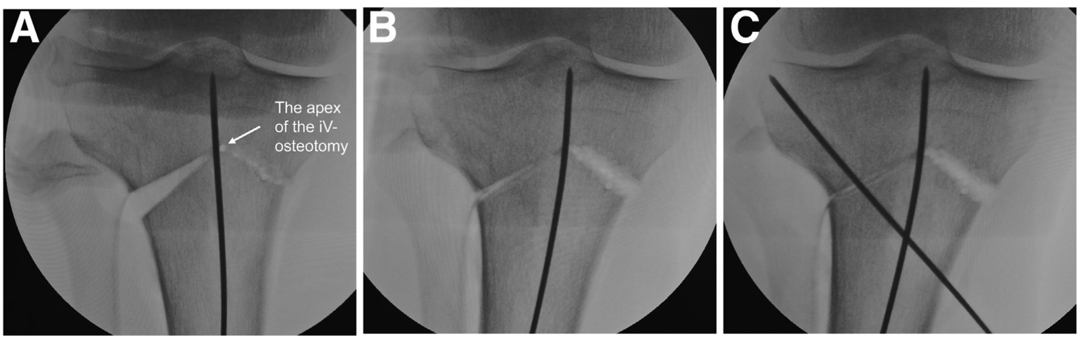

Fig 5. Valgus correction of right proximal tibia under fluoroscope. (A) Prior to the correction, a K-wire is inserted from the anteromedial aspect of the distal tibia through the apex of the V-shaped osteotomy to prevent a complete fracture at this portion. (B) A valgus force is applied manually to the tibia. (C) The assistant surgeon inserts another K-wire from the anteromedial surface of the tibia toward the lateral tibial condyle for temporary fixation. (iV, inverted V.)

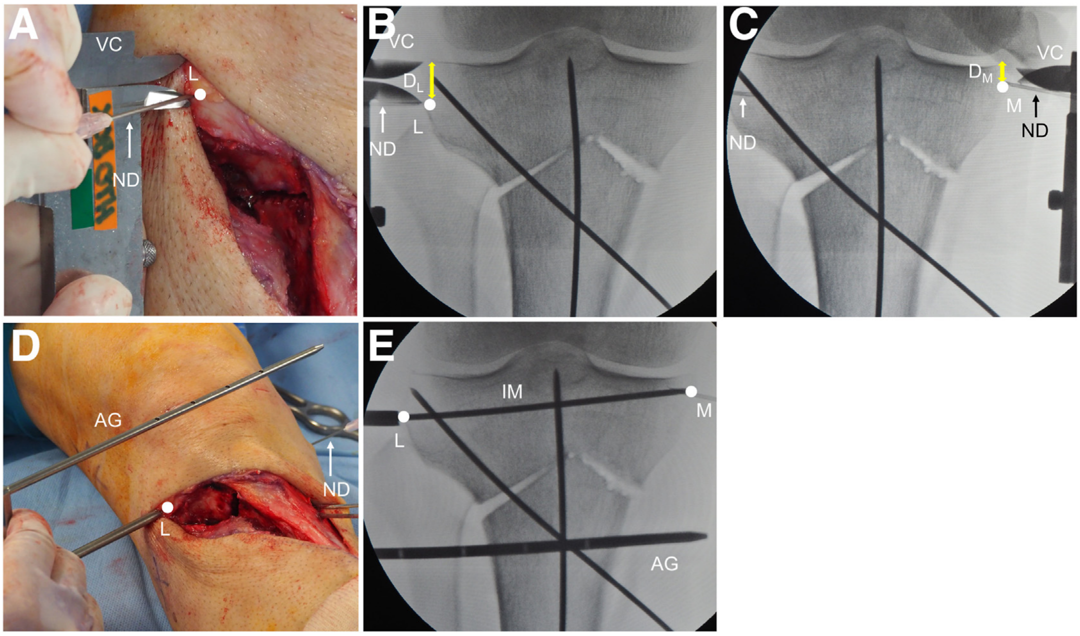

Fig 6. Technique for insertion of K-wire as intraosseous marker in right proximal tibia. (A, B) The proximal locking screw insertion point (point L) is marked with an 18-gauge needle (ND) by measuring the distance from the joint line (D_L) using a sterilized Vernier caliper (VC) (Mitutoyo) under a fluoroscope. (C) The aiming point (point M) is marked with another needle (ND) by measuring the distance (D_M) in the same manner. (D, E) Using a custom-made aiming guide (AG) (Olympus Terumo Biomaterials), a 2-mm-diameter K-wire is inserted at point L, directed toward point M. This K-wire serves as an intraosseous marker (IM) to create the first drill hole for a locking screw.

are marked with 18-gauge needles by measuring the distance of point L from the joint line and the distance of point M from the joint line using a caliper (Fig 6 A-C). Then, a K-wire is inserted at point L toward point M (Fig 6 D and E). This K-wire serves as an intraosseous marker to create the initial drill hole for a locking screw. The lateral end of the wire that is visible on the outside of the tibia is cut off.

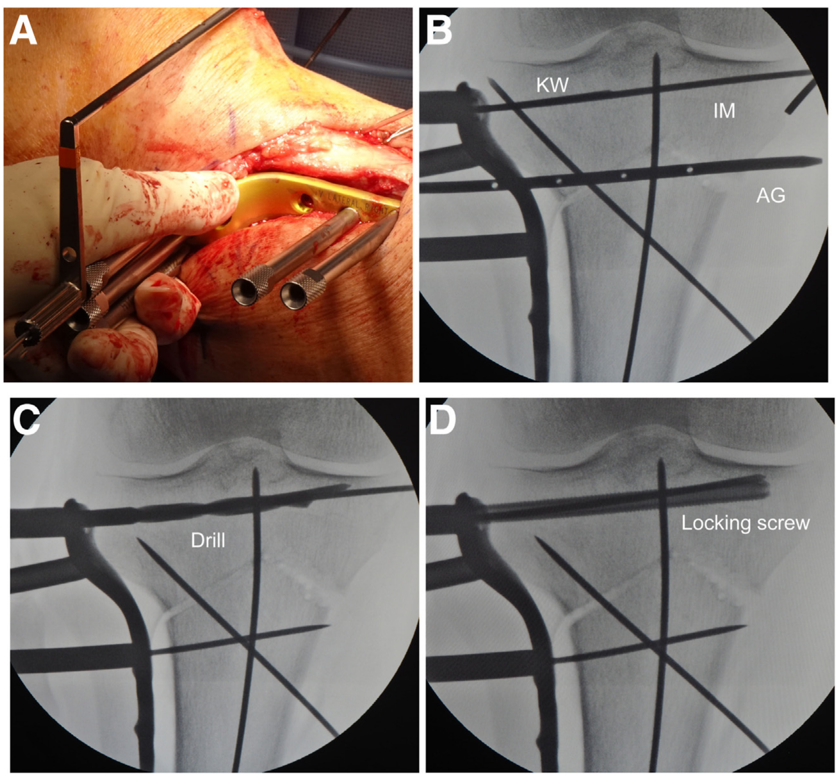

Fig 7. Technique for installation of locking compression plate (LCP) (Olympus Terumo Biomaterials) in right proximal tibia. (A) The LCP is positioned on the lateral aspect of the proximal tibia so that it is parallel to the tibial longitudinal axis. (B) A K-wire (KW) is inserted into the proximal tibia through the wire sleeve of a custom-made aiming guide (AG) (Olympus Terumo Biomaterials) attached to hole A so that this wire appears to overlap the intraosseous marker (IM). (C) The distal part of the LCP is temporarily fixed to the distal tibia by inserting another K-wire through a wire sleeve attached to hole 1. A 4.9-mm-diameter drill is inserted into the proximal tibia through the drill sleeve attached to hole B so that the drill appears to overlap the intraosseous marker. (D) The first locking screw (5.4 mm in diameter) is inserted into this bone tunnel through hole B.

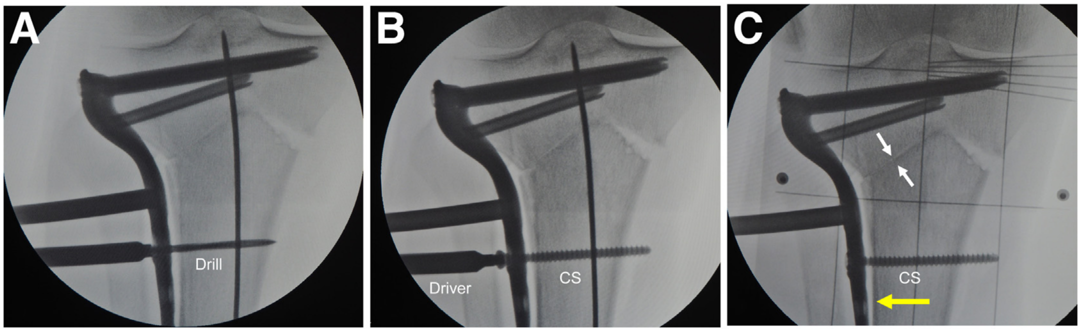

Fig 8. Technique for application of compression force to lateral hemi-wedge osteotomy site in right proximal tibia. (A) After a valgus force has been applied manually to the distal segment of the tibia, a bone tunnel is created through the compression-applying hole (hole 2) in the locking compression plate (Olympus Terumo Biomaterials). (B) A cortical screw (CS) (Olympus Terumo Biomaterials) is inserted into this bone tunnel. (C) When this screw is further turned, the distal segment of the tibia is pulled toward the locking compression plate (yellow arrow), simultaneously increasing the compression force on the osteotomy surfaces (white arrows). When this screw has been fully tightened, the planned valgus alignment of the tibia has been precisely achieved.

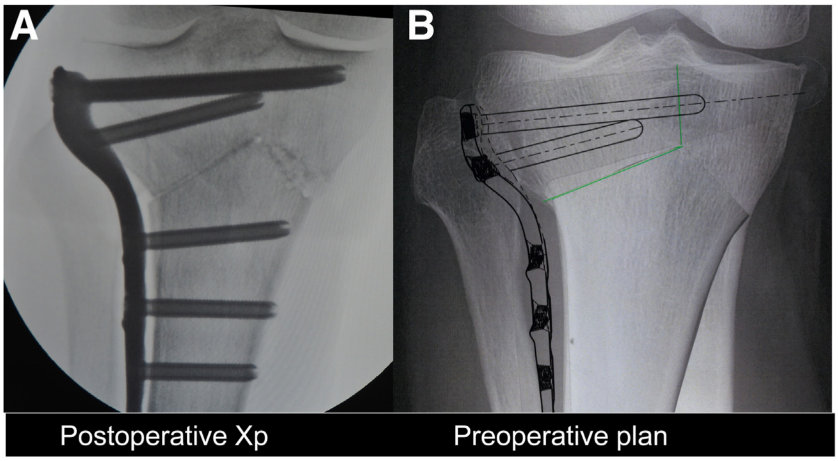

Fig 9. Postoperative radiograph (Xp) (A) and preoperative plan (B) in right proximal tibia. Morseled bone chips are implanted into the medial opening space. The osteotomized tibia is firmly fixed with a high compression force being applied to the osteotomy site while achieving the correction angle as planned preoperatively.

The LCP is placed on the lateral aspect of the proximal tibia (Fig 7A). A K-wire is inserted into the proximal tibia through a wire sleeve attached to hole A in the LCP (Fig 7B). The distal part of the LCP is temporarily fixed to the distal tibia by inserting another K-wire. Then, the surgeon inserts a 4.9-mm drill into the proximal tibia through the drill sleeve attached to hole B so that the drill appears to overlap the intraosseous marker (Fig 7C). Thus, the first locking screw is inserted into this bone tunnel exactly from point L toward point M (Fig 7D). After the intraosseous marker is pulled out medially, the other 3 locking screws are inserted into the proximal tibia (Fig 8A). Thus, the LCP is precisely installed at the planned position on the proximal segment of the tibia.

Step 2. All K-wires for temporary stabilization, except for the one traversing the apex, are removed. The surgeon applies a valgus force to the distal segment of the tibia. The assistant surgeon creates a bone tunnel through the compression hole in the LCP using a 3.2-mm drill (Fig 8A). A cortical screw is inserted into this bone tunnel (Fig 8B). When this screw is further turned, the distal segment of the tibia is pulled toward the LCP, simultaneously increasing the compression force on the osteotomy surfaces. When this screw has been fully tightened, the planned valgus alignment of the tibia has been precisely achieved (Fig 8C).

Step 3. Three locking screws are inserted into the remaining 3 distal holes of the LCP. Morseled bone chips, which are made from the wedged bone resected from the lateral tibia, are implanted into the medial opening space (Fig 9A). Thus, the osteotomized tibia is firmly fixed with a high compression force being applied to the osteotomy site while achieving the correction angle as planned preoperatively (Fig 9B).

Ligation Procedure for Fibula

The ends of the osteotomized fibula are found to be displaced mainly in the coronal plane owing to the change in the tibial shape. The displaced ends of the

Table 1. Advantages and Disadvantages of Quantitative Fixation Technique With LCP to Accurately Achieve Preoperatively Planned Tibial Correction

Advantages	
	No matter who performs the surgical procedure, tibial correction can be obtained postoperatively as planned before the procedure.
	Intuition based on a surgeon's extensive experience is not required because the technique is quantitative.
	No expensive equipment or special tools other than a sterilizable caliper are required.
	The surgical time can be reduced because the surgeon is never in doubt about the appropriate location of LCP placement during surgery.
Disadvantages	
	Radiation exposure increases because of more frequent use of fluoroscopy.
	The technique appears to be complex because it is composed of many processes.
Risks	
	Under-correction or overcorrection

LCP, locking compression plate.

osteotomized fibula are reduced using a thin elevator to ensure as much contact as possible between the osteotomy surfaces, and the previously passed polyester thread is securely tied.

Discussion

The quantitative fixation technique with an LCP includes the advantages shown in Table 1. There are some clinical pearls to perform this quantitative technique, as shown in Table 2.

Modern HTO procedures must include a technique that allows for firm fixation with a plate at the preoperatively planned angle.[12] However, iV HTO procedures using LCPs have not included such a technique.

Table 2. Pearls and Limitations of Performing Quantitative Technique

Pearls	
	The IM must be precisely inserted at point L, directed toward point M.
	The greatest attention should be paid to apply the first drilling through hole A in the LCP to completely overlap the IM under fluoroscopy.
	Immediately before the bone tunnel for a CLS is created, the surgeon should apply a sufficient valgus force to bring the distal tibial cortex as close to the LCP as possible because of the following limitation of the LCP.
	During bone tunnel creation for the CLS, a drill should be inserted at the most distal portion in hole 1 or 2 because of the following limitation of the LCP.
Limitations	
	The structure of the compression-loading hole in the LCP does not allow the distal tibia to move more than 3 mm proximally.
Risks	
	Under-correction or overcorrection

CLS, compression-loading screw; IM, intraosseous marker; LCP, locking compression plate.

Table 3. Advantages and Limitations of Inverted V−Shaped HTO Procedure

Absolute advantages	
	Fewer postoperative problems (compare MOWHTO and LCWHTO)
	No changes in leg length, patellar height, or PTS
	No changes in bone mass in proximal tibia
	Minimal deformation of proximal tibia
	Early bone union at osteotomy site
	Improvement in patellofemoral congruity in knees with patellofemoral OA
Relative advantages	
	Less damage to medial collateral ligament (compare MOWHTO)
	No vacant space in tibia immediately after surgery (compare MOWHTO)
	Lateral plate installation can reduce incidence of irritation and infection due to medial plate installation (compare MOWHTO)
	No need to harvest iliac bone graft or use artificial bone material (compare MOWHTO)
	Technically easier with fewer postoperative problems (compare LCWHTO)
	Decreased amount of posterior periosteum release
	Easier to resect out lateral bone wedge because volume is smaller (one-eighth)
	Easier to make full contact between 2 osteotomized surfaces
	Easier to apply high compression force to osteotomy site using LCP
Limitations	
	Fibular osteotomy is needed (compare MOWHTO)
	Tibialis anterior muscle must be released from tibia (compare MOWHTO)
	Technically more demanding than MOWHTO procedure
Risks	
	Peroneal nerve palsy
	Compartment syndrome
	Correction loss
	Delayed union
	Nonunion
	Infection

HTO, high tibial osteotomy; LCP, locking compression plate; LCWHTO, lateral closed-wedge high tibial osteotomy; MOWHTO, medial open-wedged high tibial osteotomy; OA, osteoarthritis; PTS, posterior tibial slope.

Therefore, we apply the described quantitative fixation technique. As a result, cases in which overcorrection or under-correction is detected on radiographs taken after completion of iV HTO surgery have disappeared in our clinical practice. Thus, the development of this quantitative plating technique has established iV HTO procedure using LCPs as one of the modern HTO techniques. The iV HTO technique using an LCP has many advantages, as shown in Table 3.[2,8,9] The equipment required for the iV HTO procedure is shown in Table 4.

Disclosures

All authors (T.K., K.Y., E.K., K.Y., J.O., N.I., T.Y.) declare that they have no known competing financial

Table 4. Equipment for Inverted V—Shaped HTO Procedure

Equipment	Brand Name (Manufacturer)
Retractor	Radiolucent Retractor (Olympus Terumo Biomaterials)
Oscillating saw	Micro Sagittal Blade (Hall Instruments—ConMed)
Lateral wedge osteotomy guide	Protractor-Installed Wire Insertion Guide (Olympus Terumo Biomaterials)
Medial osteotomy guide	Parallel Drill Guide (Olympus Terumo Biomaterials)
Caliper	Vernier caliper (Mitutoyo)
Aiming guide	Wire Navigator Guide (Olympus Terumo Biomaterials)
Locking compression plate	TriS Inverted-V Lateral HTO Plate (Olympus Terumo Biomaterials)

HTO, high tibial osteotomy.

interests or personal relationships that could have appeared to influence the work reported in this paper.

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