Technical Note

Derotational Hybrid Closed-Wedge High Tibial Osteotomy for Knee Osteoarthritis With Patellar Subluxation Caused by Tibial Torsional Deformity

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Abstract: Patellar subluxation and recurrent dislocation are commonly treated with medial patellofemoral ligament reconstruction, and patients with predisposing factors for these problems often require additional bony realignment procedures. However, these procedures mainly address problems in the axial plane, and patients with medial-compartmental knee osteoarthritis may require further realignment in the coronal plane. In this Technical Note article, we introduce our technique for derotational hybrid closed-wedge high tibial osteotomy. Using this technique, simultaneous 3-dimensional realignment in the axial, coronal, and sagittal planes can be achieved in patients with medial compartmental knee osteoarthritis and patellar subluxation caused by a tibial torsional deformity. The indications for the technique and the preoperative planning assessments involving a static torsional deformity analysis on computed tomography images and a dynamic gait analysis by our walking-on-paper method are presented. This is followed by a detailed description of the surgical procedure, together with consideration of the pearls and pitfalls of the procedure. A video of the surgery performed in a representative case with medial knee osteoarthritis and patellar subluxation in the right knee owing to an outward tibial torsion deformity is also provided.

Medial patellofemoral ligament reconstruction has become a widely accepted surgical procedure for patellar subluxation or recurrent dislocation.[1,2] However, there are multiple predisposing factors for these problems, including increased tibial tuberosity—trochlear groove (TT-TG) distance, increased femoral anteversion, and/or outward tibial torsion.[3-5] Accordingly, bony realignment should be considered in cases with these predisposing factors. A distal realignment procedure, such as the Elmslie—Trillat or "crosse de hockey" procedure, is indicated for cases with increased TT-TG distance.[6,7] Derotational distal femoral osteotomy[8] or high tibial derotational osteotomy[9,10] may solve the problems for cases with femoral anteversion or tibial outward torsion, respectively.

Although medial patellofemoral ligament reconstruction and/or realignment surgeries in the axial plane can be sufficient for patellofemoral problems, additional coronal planar realignment may be needed in cases with medial compartmental osteoarthritis (Fig 1A). Hybrid closed-wedge high tibial osteotomy (HCWHTO) (Fig 1B)[11-13] may be a practical option to simultaneously enable 3-dimensional (3D) realignment (Fig 2) in the axial,[12] coronal,[11-13] and sagittal planes.[14] The purpose of this Technical Note is to introduce our derotational HCWHTO procedure.

Definition of Derotational HCWHTO

The term "hybrid" is derived from the hybrid nature of lateral closing and medial opening by creating an intentionally disrupted medial cortex.[11] Originally, HCWHTO was reported to achieve better postoperative

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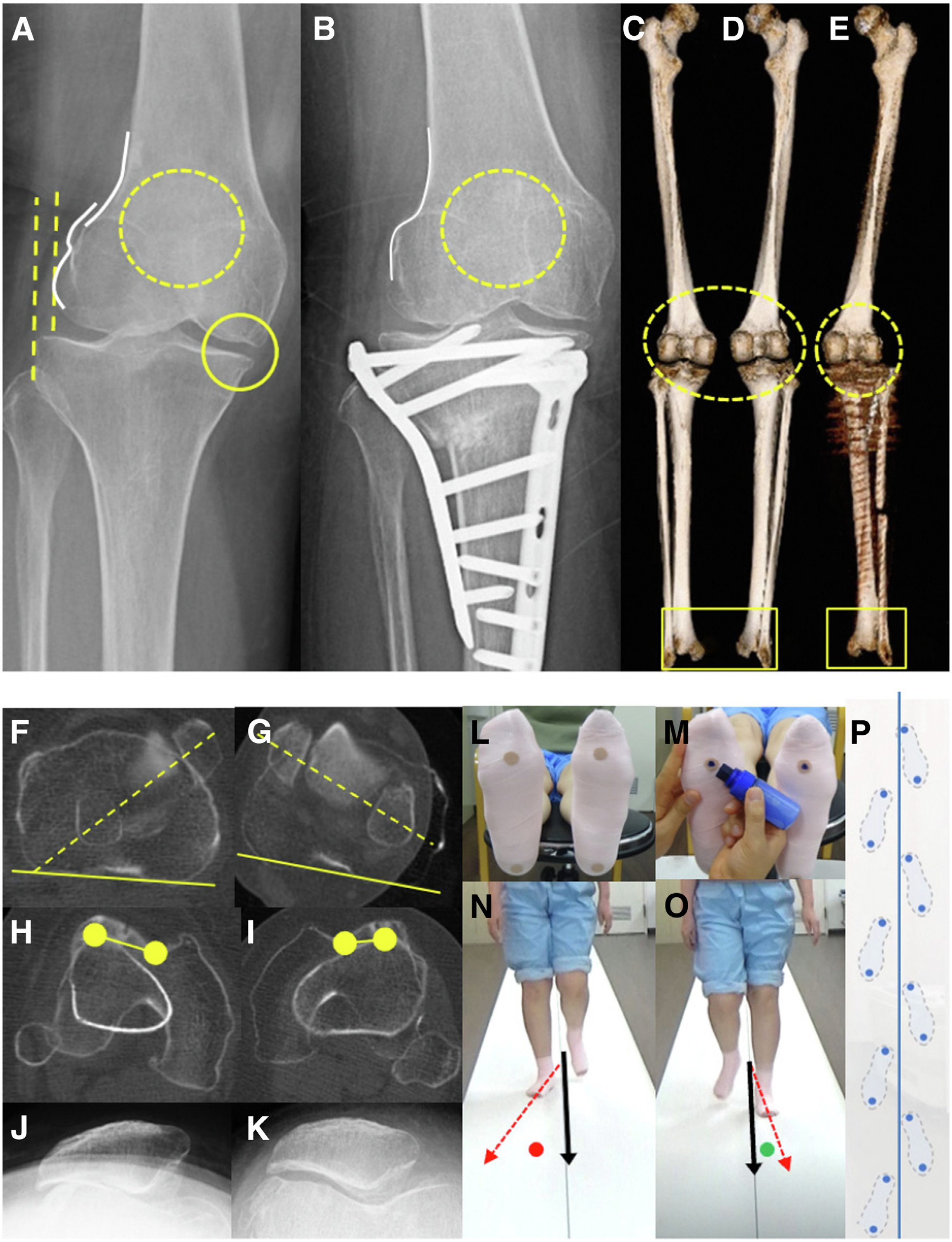

Fig 1. Image evaluation (A-K) and dynamic analysis (L-P) using our original walking-on-paper (WOP) method for a patient with outward torsion of the right tibia. (A) Standing anteroposterior (AP) radiograph of the affected right knee, oriented with the patella forward (yellow dashed circle). Because of the lateral patellar subluxation caused by the outward deformity of the tibia, the femur is demonstrated with internal rotation (indicated by the oblique view of the lateral femoral condyle; white lines) despite the true AP view of the tibia. Medial joint narrowing with osteophytes is detected (yellow circle), and the tibia is laterally

patellar position and reduction of the TT-TG distance with no intent for derotation.[12] Thus, we have named the procedure “derotational HCWHTO” to indicate the requirement for stricter rotation control to reduce the tibial torsion through the use of reference Kirschner wires (K-wires) to measure the derotation angle.

Indications and Preoperative Planning

Indications

The indications (Fig 1 C-K) for derotational HCWHTO are (1) positive anterior knee pain; (2) patellofemoral osteoarthritis with lateral shift and tilt of the patella; (3) TT-TG distance ≥15 mm; (4) bilateral tibial torsional difference ≥10°; (5) bilateral femoral torsional difference <5°; (6) presence of painful medial compartmental osteoarthritis; (7) mechanical medial proximal tibial angle[15] ≤85°; and (8) no age restriction if the patient is skeletally mature.

Preoperative Planning in the Transverse Plane

Superimposed views of computed tomography (CT) images are used for the static torsional deformity analysis. The static femoral and tibial torsions are defined as the angle between the femoral neck line and the femoral posterior condylar tangent and the angle between the tibial posterior condylar tangent and the bisector of the bimalleolar ellipses, respectively.[16] However, as the outward tibial torsion may be compensated by increased hip internal rotation during walking,[17] derotational correction based only on the static analysis could induce over-internal rotation. To avoid this error, we routinely evaluate the dynamic torsional difference between the right and left legs by measuring the foot progression angle (FPA) using our original walking-on-paper method (Fig 1 L-P and Video 1). The FPA is defined as the angle made by the long axis of the foot from the heel to the second metatarsal head and the line of progression of gait.[18,19] At the final planning in the transverse plane, the rotational correction angle planned by the static analysis is reduced depending on the FPA.

Preoperative Planning in the Coronal Plane

The target postoperative weight-bearing line ratio[20] is 60% to 70% on a standing frontal lower-extremity radiograph. However, the patella is routinely oriented forward on this radiograph, and this orientation can generate planning errors because the patella-forward view actually corresponds to the internally rotated view of the knee in cases with patellar subluxation. To prevent this error, 3D-CT views of the whole leg are taken (Fig 1 C-E). Among the multiple 3D-CT views, the true posteroanterior view showing the medial and lateral condyles with no obliquity is chosen for preoperative planning (Fig 1 C-E).[21] A digital surgical planning tool (mediCAD; Hectec, Altdorf/Landshut, Germany) is applied both to the whole-leg radiograph and the whole-leg 3D-CT view, and the planning is made by reference to both values.

Surgical Technique (With Video Illustration)

Arthroscopic Procedure

The operation is performed with the patient in the supine position under general anesthesia (Video 1). The opposite leg is placed lower than the operative leg to

translated (white dashed lines) with a medial tilt of the joint line. (B) Standing AP radiograph of the right knee at 3 months after the dual-plating hybrid closed wedge high tibial osteotomy procedure. The patella is placed at the center of the contour of the bilateral femoral condyles (yellow dashed circle). Both the tibia and the femur reveal the true AP view without obliquity of the lateral femoral condyle (white line). (C) Posteroanterior (PA) 3-dimensional (3D) computed tomography (CT) view of the unaffected whole left leg showing the medial and lateral condyles. Although there are multiple possible 3D-CT views, the true PA view should be chosen. The true view shows the medial and lateral condyles with no obliquity (yellow dashed circle). The ankle also shows the true PA view (yellow rectangle). (D) True PA 3D-CT view of the right leg. The laterally shifted patella (yellow dashed circle) and external rotation of the ankle joint (yellow rectangle) can be observed. (E) Postoperative true PA 3D-CT view of the right leg. The obliquity of the ankle joint and the medially tilted joint line are corrected (yellow rectangle and yellow dashed circle, respectively) by the internally rotational valgus osteotomy. (F) Superimposed axial CT view of the right tibia. The tibial torsion, defined as the angle between the tibial posterior condylar tangent (yellow line) and the bisector of the bimalleolar ellipses (yellow dashed line), is 37°. (G) Superimposed axial CT view of the left tibia demonstrates tibial torsion of 22° (yellow line and yellow dashed line). This implies that the right tibia has an outward torsion of 15° compared with the healthy side based on the static analysis. (H) Superimposed axial CT view of the right knee created from slices that include the tibial tuberosity (TT) and the trochlear groove (TG). The TT-TG distance (yellow double-headed line) is 26 mm. (I) Superimposed axial CT view of the left knee shows a TT−TG distance (yellow double-headed line) of 18 mm. This implies that the center of the outward torsion is located above the tuberosity. (J) Preoperative skyline view with the knee flexed to 30° demonstrates lateral subluxation of the patella. (K) The subluxation is completely improved on the skyline view at the 2-year follow-up after plate removal. (L) Preparation for the WOP method. Patches are attached at the center of the heel and the second metatarsal head to indicate the foot orientation, i.e., the long axis of the foot. (M) The patches are stained with ink. (N) Dynamic torsional analysis by the WOP method. A black line placed over the walkway aids the subject to reproduce the foot progression angle (FPA; red circle), defined as the angle between the heading direction (black arrow) and the foot orientation (red dashed arrow). The right foot shows excessive external orientation. (O) The green circle indicates the left FPA, which is smaller than the right FPA. (P) The mean FPA is calculated from a 10-m gait analysis.

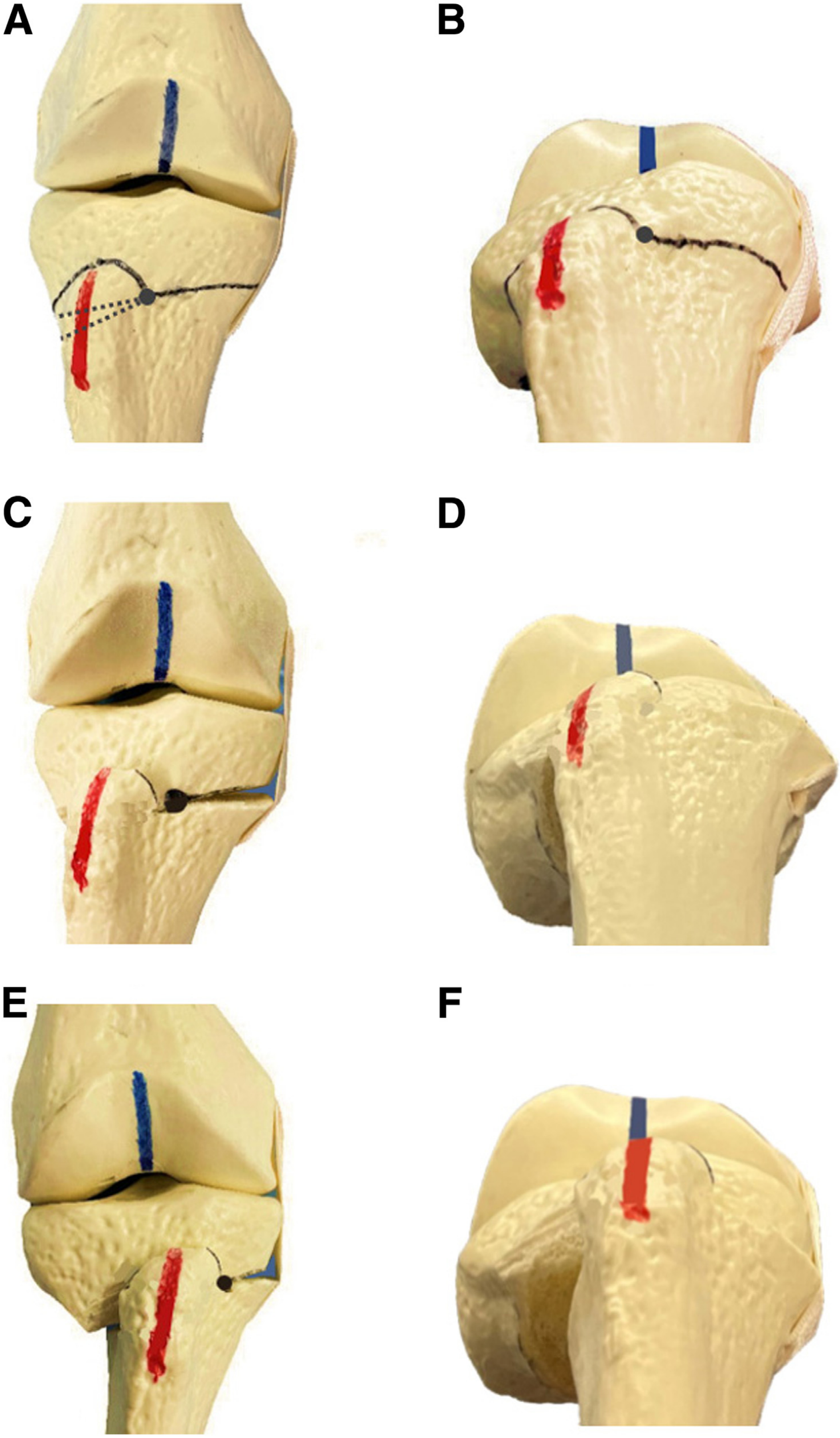

Fig 2. Principle of the derotational hybrid closed-wedge high tibial osteotomy (HCWHTO) procedure. A bone model of a right knee with an external torsional deformity of the right tibia is used. The blue and red lines represent the bottom of the trochlear groove and the top of the tibial tuberosity, respectively. (A) The preoperative anteroposterior view demonstrates a lateral position of the tibial tuberosity with respect to the trochlear groove. (B) A large tibial tuberosity−trochlear groove (TT-TG) distance is confirmed on the skyline view. (C) Ordinary 2-dimensional HCWHTO after wedge closure. Despite the corrected varus deformity, the external torsional deformity cannot be reduced. (D) Axial view shows the remaining large TT-TG distance. (E) Derotational HCWHTO after wedge closure. The distal part of the osteotomy is internally rotated at the osteotomized site. (F) Axial view from the distal tibia after the derotational HCWHTO procedure. Owing to the internal rotation of the distal part, the TT-TG distance is significantly reduced.

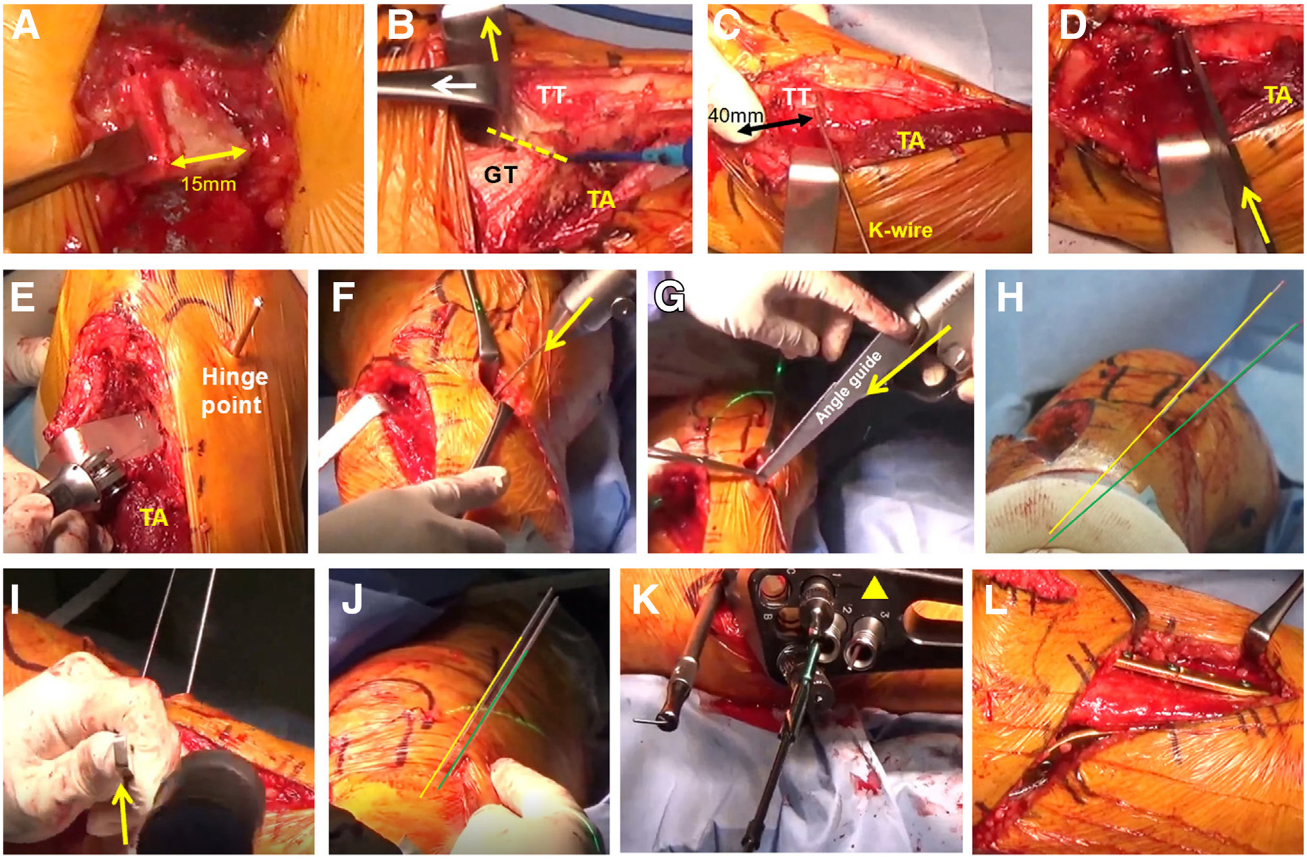

Fig 3. Soft-tissue management (the right leg is exposed). (A) The fibula is segmentally resected at its midportion, approximately 15 mm in length (yellow double-headed arrow). During the fibular osteotomy, the patient's heel is placed on a pillow to make the posterior muscles droop. (B) The tibial skin incision begins 1cm proximal to the fibular head, runs through Gerdy's tubercle (GT), and passes 1 cm lateral to the tibial anterior margin. After detaching the tibialis anterior muscle (TA), the lateral patellar retinaculumis incised along the patellar tendon edge. The patellar tendon and infrapatellar fat pad are gently retracted anteriorly (yellow arrow) and proximally (white arrow), respectively. A line for the ascending osteotomy is drawn using an electrosurgical knife between the tibial tuberosity (TT) and the GT (yellow dashed line). (C) Two Kirschner wires (K-wires) as the cutting guide are inserted at 40-mm distal from the joint line (black double-headed arrow). The thickness of the anterior flange, i.e., the insertion point of the first K-wire, is set to 15 mm from the anterior margin of the TT. (D) Following the ascending osteotomy, the proximal oblique osteotomy is performed using a micro-oscillating saw and a chisel (yellow arrow) immediately distal to the guide K-wires. (E) The knee is then flexed to create room for posterior retraction, and the distal oblique osteotomy is completed with a micro-reciprocating saw by reference to the K-wire inserted into the hinge point that divides the oblique osteotomy line in a 2:1 ratio. The posteromedial cortex of the proximal oblique osteotomy line is left uncut. (F) With the knee extended, before closing the wedge, the first K-wire for the rotation guide is inserted (yellow arrow) just distal to the joint line and perpendicular to the proximal tibial surface. (G) The second K-wire for the rotation guide is inserted (yellow arrow) using an angle guide that corresponds to the preoperatively planned derotation angle. (H) An intraoperative photograph is taken from the bottom of the foot and sent to the picture archiving and communication system (PACS). The angle is confirmed on the PACS (yellow and green lines). (I) The remaining posteromedial cortex is cut with a chisel (yellow arrow) and all the osteotomies are completed. (J) The osteotomized wedge is gradually closed by applying a valgus and internally rotational force until the 2 reference K-wires are parallel to each other (yellow and green lines). (K) Lateral plate fixation with a TomoFix Lateral High Tibia plate using a Reduction-Insertion-Compression Handle (RICH) device (yellow triangle) is performed. (L) A medial plate is added to enhance the rotational stability.

facilitate lateral retinacular release from the medial side of the knee. First, arthroscopic meniscal resection and/or repair are performed through anterolateral and anteromedial portals. Next, lateral retinacular release is performed using a scope inserted through the anteromedial portal and a radiofrequency electrode system in the superomedial portal, created approximately 4 cm proximal to the superomedial corner of the patella. Gentle knee hyperextension achieved by placing a small pillow beneath the patient's heel can help the passage of the instruments through the patellofemoral joint.[22] The lateral retinaculum is released from near the distal end of the patella to just beyond the proximal end of the patella.

Table 1. Pearls and Pitfalls of the Derotational Hybrid Closed-Wedge High Tibial Osteotomy Procedure

Pearls
Realignment in both the transverse and coronal planes can be obtained simultaneously.
The rotational angle can be easily controlled by 2 reference Kirschner wires without an external fixator because the superficial MCL works as a tension band.
Use of the RICH device facilitates the coronal realignment.
Pitfalls
The static torsional deformity analysis using superimposed views of computed tomography images may induce planning errors because of the compensatory increased internal rotation of the hip joint during walking. Dynamic gait analysis should be considered in the preoperative planning.
Application of excessive compression with a nut (Pull Reduction Instrument) to provide compressive force to the osteotomized site may lead to lateralization of the tibial tuberosity. Continual awareness of TT—TG distance <15 mm is required during the compression procedure.

MCL, medial collateral ligament; RICH, Reduction-Insertion-Compression Handle; TT-TG, tibial tuberosity—trochlear groove.

Table 2. Risks and Limitations of the Derotational Hybrid Closed Wedge High Tibial Osteotomy Procedure

Risks
The RICH device can be used as a guide for minimally invasive surgery. When inserting the distal drill sleeves through the tibialis anterior muscle, special care should be taken to avoid injuring the branches of the deep peroneal nerve.
Internal rotation of the distal part of the osteotomy can be a risk factor for peroneal nerve palsy. Peroneal nerve release is recommended when the correction angle exceeds 10°.
Limitations
Although the tibial torsion is significantly larger than the normal value, derotational HCWHTO may not be indicated for cases without a torsional difference between the right and left sides.
In cases in which the torsional center is located below the tibial tuberosity, i.e., outward tibial torsion without patellar subluxation, the derotational osteotomy should be performed below the tuberosity. Derotational HCWHTO is contraindicated in such cases.

HCWHTO, hybrid closed-wedge high tibial osteotomy; RICH, Reduction-Insertion-Compression Handle.

Osteotomy

The opposite leg is turned back to the horizontal position, and the fibula is segmentally resected according to an ankle-angle-adjusting procedure (Video 1, Fig 3).[23] An anterolateral curved incision is made for the tibial osteotomy, and an anteromedial longitudinal incision is added for medial plating because a derotational osteotomy is more unstable than a 2-dimensional osteotomy. Following an ascending osteotomy, a proximal oblique osteotomy is performed under K-wire guidance with a complete cut of the medial cortex. After removing the guide K-wires, a 3.0-mm K-wire for the hinge point is inserted that divides the proximal oblique osteotomy line in a 2:1 ratio. A distal oblique osteotomy is performed toward the hinge-K-wire. After removing the wedge, the remaining posteromedial cortex beyond the hinge is completely cut using a chisel under fluoroscopic control.

Control of Rotation

Once the osteotomy is complete, 2 K-wires are placed proximal and distal to the osteotomy in the desired "deformity angle" for correction (Video 1, Fig 3).[16] A photograph of the K-wires is taken from the bottom of the foot and sent to a picture archiving and communication system. After confirmation of the rotation angle on the picture archiving and communication system, the osteotomized wedge is closed by applying a valgus and internally rotational stress until the two reference K-wires are parallel to each other.

Plate Fixation

A TomoFix Lateral High Tibia plate (Johnson & Johnson, New Brunswick, NJ) connected to a Reduction-Insertion-Compression Handle device (DePuy Synthes Japan, Tokyo, Japan) is placed on the lateral aspect of the tibia (Video 1, Fig 3). Following temporary fixation with 3 K-wires and a Pull Reduction Instrument, locking screws are inserted through the drill sleeves in the Reduction-Insertion-Compression Handle device. A medial plate to enhance the rotational stability, TomoFix Medial High Tibial Plate (Synthes GmbH, Solothurn, Switzerland) or TriS Small Plate (Olympus Terumo Biomaterials, Tokyo, Japan), is inserted from the anteromedial skin incision and fixed. The pearls and pitfalls of the derotational HCWHTO are listed in Table 1.

Postoperative Rehabilitation

Full weight-bearing walking exercise and range-of-motion exercises are allowed on the first postoperative day and then gradually advanced as tolerated.

Discussion

Severe patellofemoral osteoarthritis with patellar subluxation occasionally occurs in association with medial compartmental osteoarthritis and has consistently been a relative contraindication for osteotomies and an indication for total knee arthroplasty.[24] Although combined open-wedge high tibial osteotomy/closed-wedge high tibial osteotomy and tibial tuberosity ventralization osteotomies may be an option,[25,26] complicated dual-osteotomy procedures can increase the risk of infection and/or unintended fracture. Furthermore, because these combinations cannot improve the subluxation with patellar tilt caused by torsional deformity, derotational HCWHTO appears to be the best solution for enabling 3D correction.

When a derotational osteotomy is performed at the femoral or tibial shaft, use of Schanz screws with an external fixator is recommended to prevent irreducible displacement of the osteotomized site.[16] However, in

HCWHTO,[11-14,27] 2 K-wires can be safely used as rotational references without an external fixator because the superficial medial collateral ligament works as a tension-band.[13] As peroneal nerve palsy is the greatest risk associated with the procedure,[16] decompression of the nerve[28] is performed in cases with derotational correction ≥10°. The other risks and limitations are listed in Table 2.

In conclusion, derotational HCWHTO facilitates both rotational and coronal realignment for medial compartmental and patellofemoral osteoarthritis with patellar subluxation arising from outward tibial torsion.

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