



Opening Wedge High Tibial Osteotomy Using Combined Computed Tomography-Based and Image-Free Navigation System

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Abstract: For opening wedge high tibial osteotomy (OWHTO), it is recommended that the osteotomy line is parallel to the medial tibial posterior slope (TPS) in the sagittal view and that the alignments are simultaneously controlled in the coronal and sagittal views. Here combined computed tomography (CT)-based and image-free navigation systems were used for intraoperative reference during OWHTO. Using the CT-based navigation, 2 entry points for insertion of Kirschner wires were preoperatively set up and an accurate osteotomy plane was intraoperatively duplicated. Preoperative planning anticipated a femorotibial angle of 170° , representing a weight-bearing ratio of 62.5%, on the whole-leg radiograph. The original TPS in the sagittal view was aimed to be preserved postoperatively. The hip-knee-ankle (HKA) correction angle was preoperatively measured on the whole-leg radiograph, and the HKA angle and flexion angle were intraoperatively monitored in real time using the image-free navigation. We have introduced an operative technique for OWHTO using CT-based and image-free navigation systems. We expect that this method, with the osteotomy plane parallel to the tibial plateau plane in the sagittal view and simultaneous control of coronal and sagittal alignments, will enable actuation of accurate alignment in the 2 planes and lead to improvements in patient activity in future.

Navigation systems around the knee are mainly used in total knee arthroplasty (TKA) to acquire accurate positioning of the femoral and tibial components and coronal alignment in the whole lower leg. Meanwhile, image-free navigation in opening wedge high tibial osteotomy (OWHTO), in which the postoperative coronal alignment directly affects the clinical results,¹ has begun to be reported.^{2,3} For OWHTO, duplication of the preoperative planned osteotomy plane and confirmation of the corrected or aimed angle during the operation are necessary. The osteotomy line is recommended to be parallel to the medial tibial slope in the sagittal view, with

simultaneous control of the coronal and sagittal alignments.^{4,5} Therefore, we used combined computed tomography (CT)-based and image-free navigation systems for intraoperative reference in OWHTO. We introduce an operative technique for OWHTO using CT-based and image-free navigation systems.

Surgical Technique

Indications

Indications were patients with medial knee osteoarthritis or osteonecrosis at the medial femoral condyle, femorotibial angle (FTA) of $\leq 185^\circ$, and flexion contracture of $\leq 15^\circ$. Contraindications were patients with patellofemoral symptoms, anterior cruciate ligament insufficiency, and lateral tibiofemoral joint space narrowing on radiographs.

Preparation for CT-Based Navigation

A Stryker Knee Navigation System (Stryker, Kalamazoo, MI) was used in both the CT-based and image-free navigations. CT images of the whole lower extremity were projected as 1.5-mm-thick slices using a SOMATOM Sensation 16 (Siemens, Munich, Germany). Orthomap3D software (Stryker) on a PC installed data from the CT images and was used in

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preoperative planning for CT-based navigation. The software enabled us to select anatomic landmarks and determine 3-dimensional linear and angular measurements by simultaneous reference to the sagittal, coronal, and axial views. The sagittal and coronal planes were defined as described previously.⁵ The osteotomy plane was made parallel to the tibial plateau plane in the sagittal view, being directed from 35 mm distal to the medial tibial plateau to the safe zone distal to the lateral tibial plateau in the coronal view.⁶ To create an accurate osteotomy plane using 2 Kirschner wires, 2 entry points for insertion were set up (Fig 1, Video 1). Five points for registration of the 3-dimensional-CT navigation system were located in the medial and lateral malleoli, fibular head, tibial tuberosity, and anterior corner of the medial tibial plateau.

Preparation for Image-Free Navigation

The radiographs were projected using a Fuji Computed Radiography System (Fujifilm, Tokyo, Japan), and the various angles were measured with Fujifilm OP-A

software (Fujifilm). Anteroposterior (AP) and lateral whole-leg radiographs were obtained with the patients in a standing position, together with a skyline view of the knee. The image-free navigation system monitored the hip-knee-ankle (HKA) angle and flexion angle in real time. Preoperative planning anticipated an FTA of 170° , representing a weight-bearing ratio of 62.5%, on the whole-leg radiograph.^{5,7} Therefore, the preoperative HKA angle was measured, and the postoperative FTA of 170° was converted to the HKA angle in advance on the AP whole-leg radiograph. In the example case shown in Figure 2, the patient had primary osteoarthritis of the left knee. The preoperative whole-leg AP radiograph showed an FTA of 181.5° , weight-bearing line ratio of 20.1%, and HKA angle of 6.5° varus. The aimed HKA angle and change in HKA angle were calculated as 1.5° valgus and 8° , respectively.

Preoperative Set-Up

The patient was positioned supine on the operating table. A thigh tourniquet was inflated to 300 mmHg.

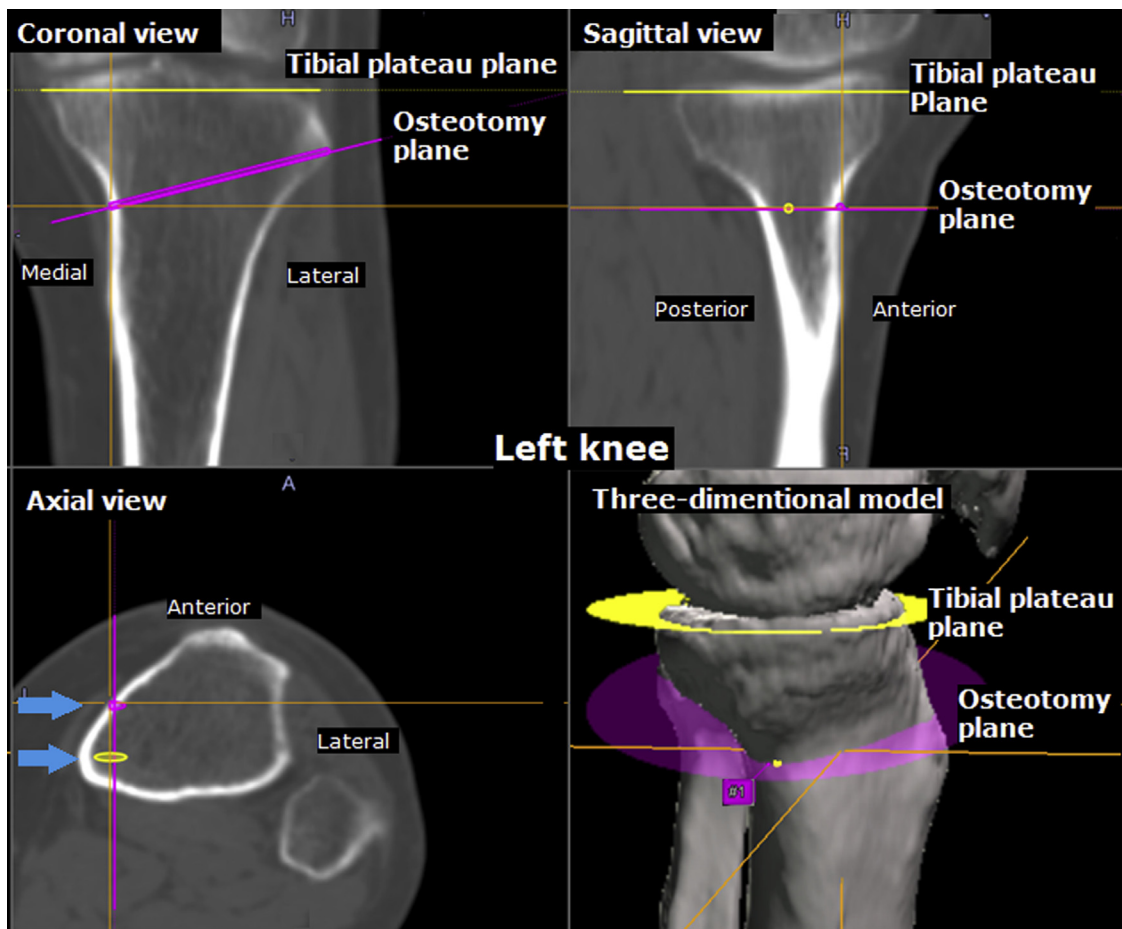


Fig 1. Planning for the computed tomography (CT)-based navigation of the left knee with the patient in the supine position. The osteotomy plane (purple) was directed from 35 mm distal to the medial tibial plateau to the safe zone distal to the lateral tibial plateau in the coronal view and was planned to be parallel to the tibial plateau plane (yellow) in the sagittal view. The blue arrows show the insertion entry points of the 2 Kirschner wires. The yellow tibial plateau plane and purple osteotomy plane are shown in a 3-dimensional model.

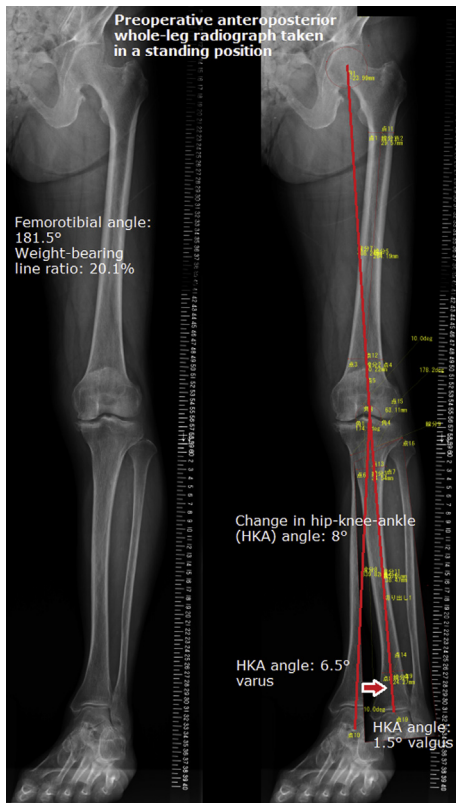


Fig 2. Preparation of the image-free navigation. The anteroposterior radiograph shows a femorotibial angle (FTA) of 181.5° and a weight-bearing line ratio of 20.1%. We aimed for a postoperative FTA of 170°, and the FTA was converted to the hip-knee-ankle (HKA) angle. The HKA angle of 6.5° varus was changed to 1.5° valgus, and the change in the HKA angle was calculated as 8°.

The ipsilateral leg was placed lower than the operative leg, thereby facilitating the approach to the medial side of the operative knee during the procedures.

Diagnostic Arthroscopy

An arthroscopic examination was carried out in all patients before OWHTO. The medial femoral condyle and tibial plateau articular cartilage were graded according to the International Cartilage Repair Society grading system.⁸ In the example case shown in [Figure 3](#), grade 4A defects involving the subchondral bone were seen in the medial femoral and tibial condyles, grade 1A intact surface with fibrillation and/or slight softening was seen in the lateral femoral condyle, and grade 1B superficial lesions and superficial fissures and cracks were seen in the lateral tibial condyle.

Approach

An approximately 4- to 5-cm incision was made longitudinally at the 4- to 5-cm medial portion of the anterior ridge of the tibia. The medial collateral ligament was released under the tibial periosteum, and the semitendinosus and gracilis tendons were left intact. In this case, the posterior soft-tissue release was extended distally.

CT-Based Navigation

Two trackers were inserted at 10 cm proximal to the knee joint line on the distal femur, and 12 cm distal to the knee joint line on the proximal tibia, to indicate the space for fixation of the plate and screws. Two trackers were also used in the subsequent image-free

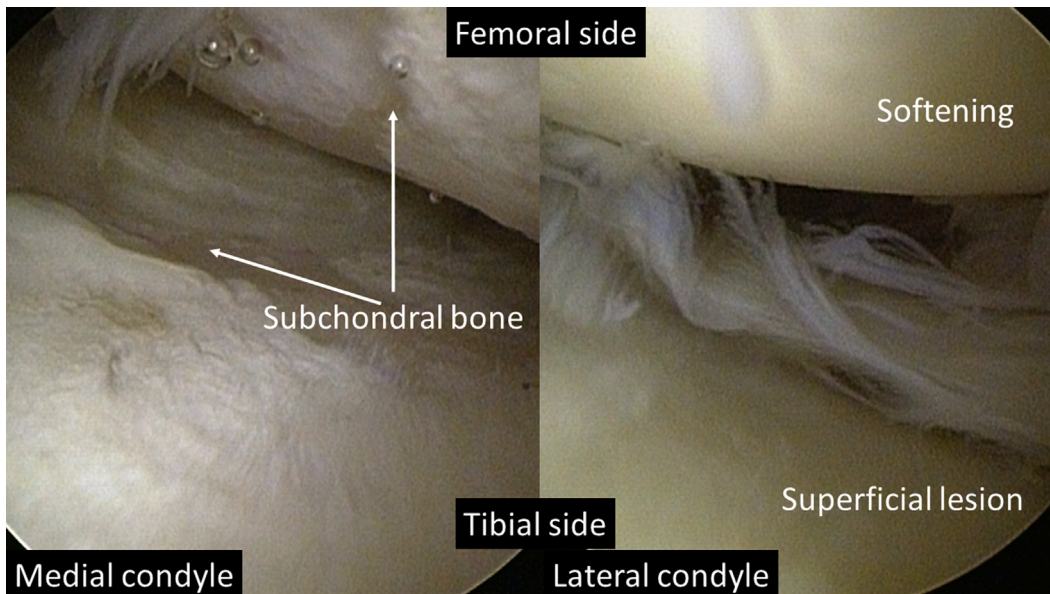


Fig 3. Arthroscopic findings, graded according to the International Cartilage Repair Society grading system, in the medial and lateral condyles. Grade 4A defects involving the subchondral bone were seen in the medial femoral and tibial condyles, grade 1A intact surface with slight softening was seen in the lateral femoral condyle, and grade 1B superficial lesions were seen in the lateral tibial condyle.

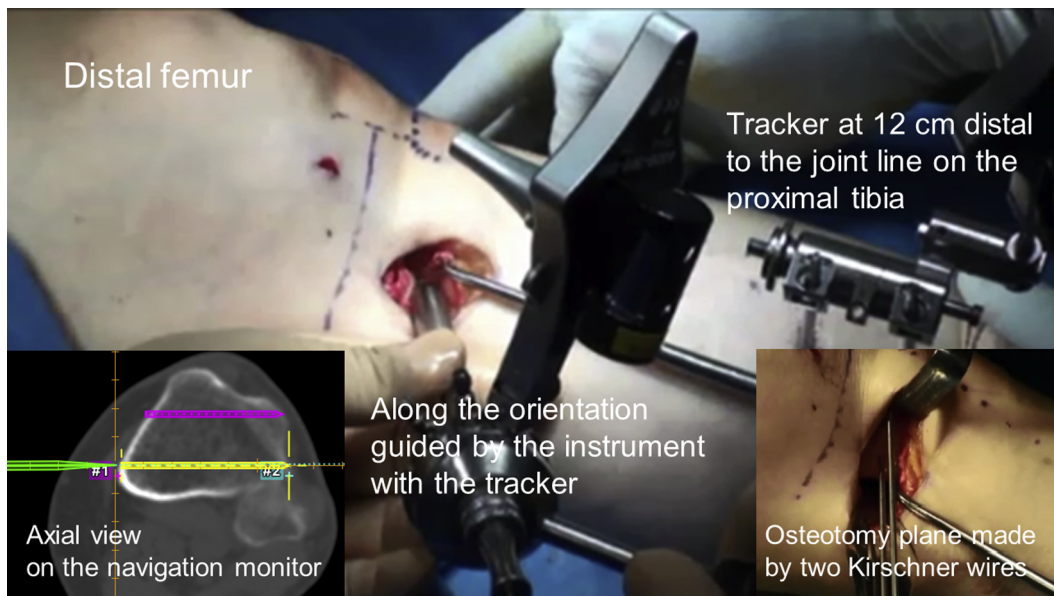


Fig 4. Intraoperatively, 2 Kirschner wires were inserted along the orientation guided by the instrument with the tracker while looking in the navigation monitor. The osteotomy plane parallel to the tibial plateau plane was made by 2 Kirschner wires.

navigation, and the camera sensor was confirmed to capture the 3-dimensional position of the trackers in space during bending action from the extension position. Five points on the skin and bone surface were registered, and the CT images and real tibial bone were matched. Two Kirschner wires were inserted through the entry points under guidance of the CT-based navigation (Fig 4).

Image-Free Navigation

The CT-based navigation was switched to the image-free navigation in the same navigation hardware. According to the monitor guidance, the hip center, medial and lateral epicondyles, AP line on distal femur, patella center, AP line on proximal tibia, and medial and lateral malleoli were registered. Before the osteotomy, the HKA angle and full extension angle were recorded. An oblique osteotomy was performed using a bone saw and chisels under the 2 Kirschner wires, leaving 10 mm of the lateral cortex intact as a hinge. A Hohmann retractor was inserted to protect the neurovascular structures behind the osteotomy site. The patellar tendon was freed from the medial border and protected using a retractor. An ascending osteotomy was performed under the tibial tuberosity at an angle of 100° to 120° to the horizontal cut in the posterior 2/3 of the tibia in the sagittal view. The first chisel was inserted into the oblique osteotomy to within 10 mm of the lateral tibial cortex. The second chisel was placed into the Kirschner wires and the first chisel to within 15 mm of the lateral cortex. The third and fourth chisels were inserted between the previous chisels to

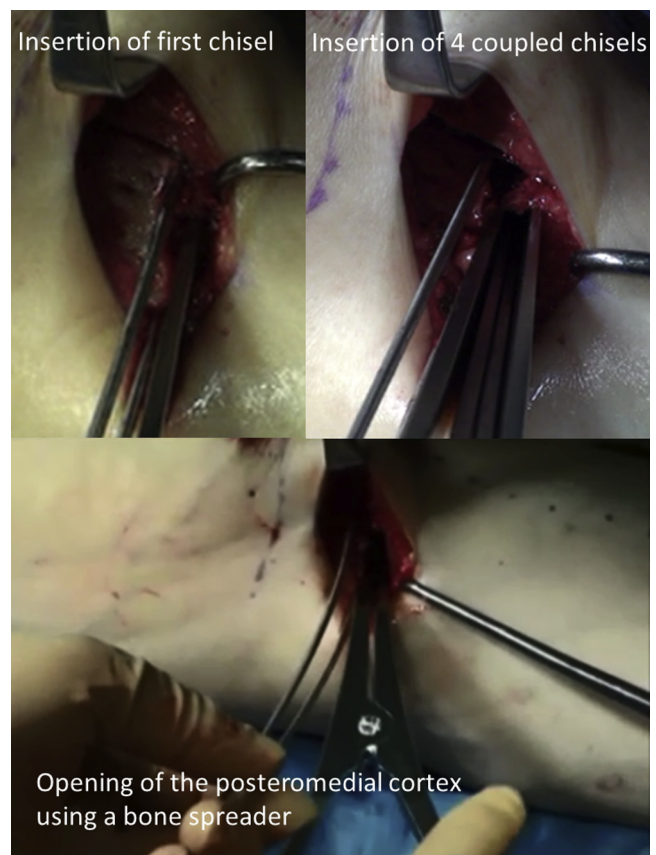


Fig 5. The first chisel was inserted into the oblique osteotomy to within 10 mm of the lateral tibial cortex. The osteotomy site was gradually opened by stepwise insertion of 4 coupled chisels. Opening of the posteromedial cortex was held using a bone spreader.

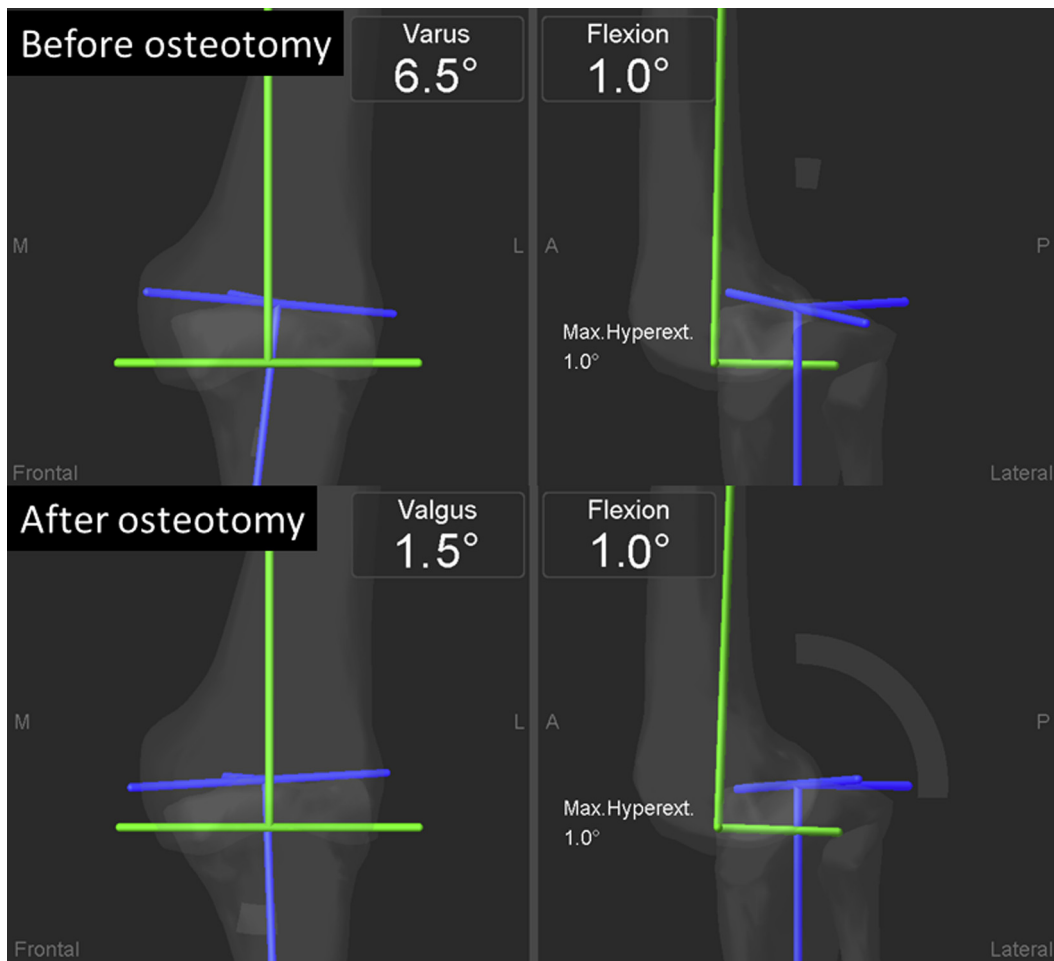


Fig 6. Intraoperatively, the hip-knee-ankle angle of 6.5° varus was changed to 1.5° valgus, and the maximum flexion angle of 1.0° was preserved because the tibial posterior slope did not change after the osteotomy.

within the depth of less than the previous one. The osteotomy site was gradually opened by stepwise insertion of 4 coupled chisels. Opening of the posteromedial cortex was held using a bone spreader (Fig 5).⁹ After the osteotomy, the varus deformity of the knee was corrected to the predicted change in the HKA angle in the coronal view. The original tibial posterior slope (TPS) in the sagittal view was aimed to be preserved postoperatively. The TPS was controlled by maintaining full extension before the osteotomy to the same degree as full extension after opening in the navigation monitor (Fig 6). The width between the medial posterior edges was measured after opening, and 2 formed quadrangular β -TCP wedges (Olympus Terumo Biomaterials, Tokyo, Japan) were inserted into the opened gap. In patients with increased TPS, release of the posterior soft tissue was added. In patients with decreased TPS, an anterior triangular wedge was inserted into the inner side, or converted to another wider wedge. The medial opening gap was fixed with TomoFix and locking screws (Synthes, Bettlach, Switzerland).

Postoperative Management

This patient received thromboembolism prophylaxis in the form of low-molecular-weight heparin and venous impulse foot pumps. Active and passive range-of-motion exercises and straight leg raising exercises were initiated on the day after surgery. Full weight bearing was permitted from 1 week postoperatively.

Postoperative Radiograph

In the example case shown in Figure 7, the AP radiograph showed an FTA of 168.4° and weight-bearing line ratio of 71.6%.

Discussion

Among the 2 types of image-based and image-free navigation systems, image-free navigation has gained popularity in TKA, OWHTO, and anterior cruciate ligament reconstruction, because of its lack of required preparation and lower radiation exposure. Furthermore, image-free navigation in OWHTO has gained relatively positive outcomes, with improved accuracy and precision of the coronal and sagittal alignments.^{2,3}



Fig 7. Radiograph showing the femorotibial angle of 168.4° and weight-bearing line ratio of 71.6%.

In this Technical Note, we performed OWHTO using combined CT-based and image-free navigation systems in one navigation device.

The outcomes of OWHTO are contributed by accurate preoperative planning and intraoperative technique.² The key for the intraoperative technique is mainly the creation of an accurate osteotomy plane and opening gap. An accurate osteotomy plane means that the osteotomy plane is parallel to the tibial plateau plane in the sagittal view, the surface of the osteotomy plane is smooth, and the upper and lower osteotomy planes are opened as the center of the aimed hinge point. An accurate opening gap means that the medial soft tissue is sufficiently released, and the anteromedial corner is opened at 67% of the width of the gap in the

Table 1. Advantages and Disadvantages of This Technique

Advantages
Decreased outlier in the coronal alignment
Decreased change in tibial posterior slope
Shorter fluoroscopy time
Disadvantages
Longer operative time
Risks of infection, fracture and hematoma on tracker pin sites

Table 2. Pearls/Pitfalls

Pearls

- CT-based navigation enables acquisition of the target osteotomy plane in the sagittal view.
- Image-free navigation is helpful for simultaneous control of the alignment in the sagittal and coronal views.

Pitfalls

- Failed tracker pin fixation may result in inaccurate postoperative alignment in the sagittal and coronal views.
- Change in tibial posterior slope (TPS) was not directly monitored using image-free navigation; therefore TPS was controlled by maintaining full extension before the osteotomy to the same degree as full extension after opening in the navigation monitor.

posteromedial corner.⁴ However, accuracy and precision in the coronal and sagittal views did not improve the clinical outcomes in the short term and the outcomes in the long term remained unclear, meaning that a future study is needed. In addition, this technique has advantages and disadvantages as well as pearls and pitfalls (Tables 1 and 2).

In conclusion, we have introduced a surgical technique for OWHTO with combined CT-based and image-free navigation systems. We expect that this method, with the osteotomy plane parallel to the tibial plateau plane in the sagittal view, will enable actuation of accurate alignment in the coronal and sagittal planes and will lead to improvement of patient activity in the future.

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