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Femoral-varus tibial-valgus osteotomy (FVTVO) for neutrally-aligned knee osteoarthritis with severe joint line obliquity enables return to sports activities: A case series study

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ABSTRACT

Background: Re-alignment surgeries for uni-compartmental knee osteoarthritis, such as high tibial osteotomy (HTO) for varus knees or distal femoral osteotomy (DFO) for valgus knees, are recognized as standard strategies. However, the treatment strategy has not been established for patients with a neutrally-aligned osteoarthritic knee with severe joint line obliquity (JLO) owing to the combination of a valgus femur and a varus tibia; i.e., type II coronal plane alignment of the knee (CPAK). total knee arthroplasty (TKA) can be an option for CPAK type II-aligned osteoarthritis in older inactive patients. Here, we hypothesized that joint line horizontalization by femoral-varus tibial-valgus osteotomy (FVTVO), which may reduce the shear stress induced by JLO, could be a treatment option for CPAK type II-aligned osteoarthritis in young active patients who wish to return to sports (RTS) activity. Our aim in this study was to evaluate the postoperative results of FVTVO with RTS.

Methods: Our indications for FVTVO are as follows: JLO >5°; mechanical medial proximal tibial angle (mMPTA) < 87°; mechanical lateral distal femoral angle (mLDFA) < 87°; typical osteoarthritis patterns for CPAK type II on magnetic resonance images, namely osteoarthritic change of the lateral tibial spine, medial slip of the femur, and/or lateral meniscal extrusion from the lateral femoral condyle; and flexion contracture <10°. We enrolled patients who wished to RTS and who had a pre-symptom Tegner score ≥5 and had completed at least a 1-year follow-up. For FVTVO, closed-wedge DFO was performed in all femurs; both closed-wedge HTO and open-wedge HTO were used in the tibia, depending on the situation. Range of motion exercises began on the first postoperative day, and full weight-bearing was permitted 6 weeks postoperatively. Jogging was permitted 3 months postoperatively after confirming bone union, and patients could gradually return to their sports activity 6–12 months' postoperatively. The Japanese Orthopaedic Association (JOA) score and knee flexion range were assessed preoperatively and at the last follow-up. Tegner activity scale scores were assessed presymptom, preoperatively, and at the last follow-up. The hip-knee-ankle (HKA) angle, JLO, mMPTA, and mLDFA were evaluated radiologically, and meniscal extrusions, osteoarthritic change, and/or bone marrow edema were assessed on magnetic resonance images.

Results: One man and two women were included in this case series. Two were competitive athletes and one was a mountain climber. The patients' ages were 69, 46, and 57 years (Case 1, 2, and 3, respectively). All patients' CPAK type was converted from type II to type V; i.e., neutral-aligned knee with a neutral joint line, postoperatively. All patients returned to their presymptom sports activity level by the final

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follow-up. The presymptom/preoperative/final follow-up Tegner scale in Case 1, 2, and 3 were 6/1/6, 5/2/5, and 7/3/7, respectively.
Conclusion: Joint line horizontalization by FVTVO for patients with a neutral-aligned knee with severe JLO provided highly satisfactory clinical results and successfully led to RTS.

1. Introduction

High tibial osteotomy (HTO), including medial open-wedge HTO (OWHTO)[1-4] and lateral closed wedge HTO (CWHTO), [5-7] for medial compartmental osteoarthritis in varus knee has become a widely accepted surgery. Currently, medial closed wedge distal femoral osteotomy (DFO) [8,9] for valgus knees and lateral closed wedge DFO combined with medial OWHTO or lateral CWHTO; *i.e.*, double-level osteotomy[10-12] for severe varus knees are also becoming more common since the launch of various around-knee osteotomy (AKO)-specific locking plates. As a result, coronal alignment correction for uni-compartmental knee osteoarthritis with a varus/valgus deformity is a well-established option. Furthermore, the high rate of return to sports (RTS) after varus/valgus-correcting AKOs has been reported[4,12-16], and the procedure provides satisfactory pain relief and improved activities of daily living.

However, in our clinical experience, we sometimes encounter neutrally-aligned osteoarthritic knees with severe joint line obliquity (JLO) owing to the combination of a valgus femur and a varus tibia.[17] When evaluating the relationship between coronal alignment and JLO, the coronal plane alignment of the knee (CPAK) is classified in accordance with MacDessi et al.[18] These authors defined the direction of the JLO as apex distal/neutral/proximal, which can be interpreted as a medially-tilted joint line/neutral joint line/laterally-tilted joint line, respectively. On the basis of the combinations of varus >3°/neutral/valgus >3° and apex distal >2°/neutral/apex proximal >2° for medially-tilted/neutral/laterally-tilted joint lines, respectively, the CPAK classification comprises nine phenotypes. Neutrally-aligned knees with medially-tilted joint lines are classified as CPAK type II.

The theoretically possible osteoarthritis patterns in type II are as follows[19] (Fig. 1A): 1) lateral subluxation of the tibia owing to medial slip of the femur; 2) osteoarthritis and/or bone marrow edema of the lateral aspect of the tibial spine, which functions as an anti-slip structure against the slip of the femoral lateral condyle; 3) lateral compartmental osteoarthritis because the lateral meniscus extrudes from the lateral edge of the lateral femoral condyle despite the lack of extrusion from the lateral tibial plateau; and 4) the medial hoop tends to be disrupted as well because of the medial femoral slip, which may cause medial meniscal extrusion from the medial tibial plateau.

Although total knee arthroplasty (TKA) can be a good candidate procedure for type II osteoarthritis when the patient is elderly and inactive, no specific treatment exists for young patients who desire RTS. Here, we hypothesized that 1) joint line horizontalization using femoral-varus tibial-valgus osteotomy (FVTVO; Fig. 1B) would be helpful for CPAK type II-aligned knee osteoarthritis by converting the type to a CPAK type V-aligned knee; namely, neutral-aligned knee without JLO (Figs. 1C), and 2) FVTVO, despite the "offsetting" double-level osteotomy without correcting the coronal alignment, enables RTS by reducing shear stress. Thus, the objective of this study was to investigate the results of FVTVO for patients

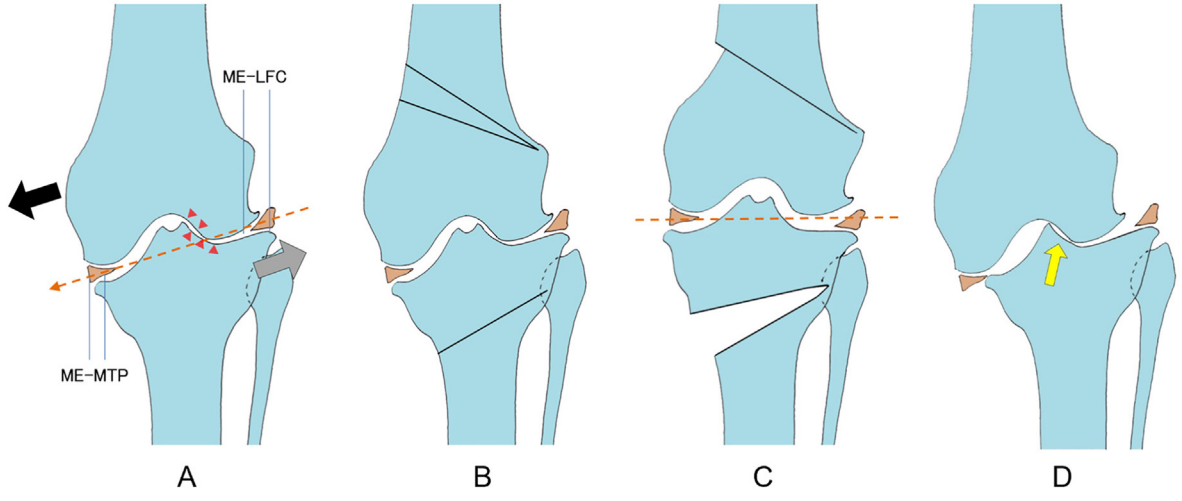

Fig. 1. Schema of the osteoarthritis in type II coronal plane alignment of the knee (CPAK) and the concept of femoral-varus tibial-valgus osteotomy (FVTVO).
A. Even with neutral alignment, the following possible lesions can be created by a medially-tilted joint line (dashed orange arrow): 1) the tibia shifts laterally (gray arrow), and the femur slips medially (black arrow); 2) because the tibial spine works as an anti-slip structure against the lateral femoral condyle, osteoarthritis and/or bone marrow edema of the lateral aspect of the tibial spine and medial aspect of the lateral condyle (red triangles) can develop; 3) the lateral meniscus extrudes from the lateral edge of the lateral femoral condyle (ME-LFC) despite the lack of extrusion from the lateral tibial plateau; and 4) the medial meniscus extrudes from the medial tibial plateau (ME-MTP). B. Osteotomy lines for FVTVO (black lines). Coronal osteotomy lines for biplanar osteotomy are not drawn to simplify the schema. C. Post-FVTVO findings. The joint line is horizontalized (dashed orange line) following medial closed -wedge distal femoral osteotomy combined with medial open-wedge high tibial osteotomy. The CPAK classification was converted from type II to type V after surgery; i.e., neutral-aligned knee with neutral joint line obliquity, which may prevent the possible lesions mentioned in panel A. D. An example of a contraindication for FVTVO. Severe lateral tibial subluxation with a "single tibial spine" owing to excessive abrasion of the lateral tibial spine is a contraindication. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

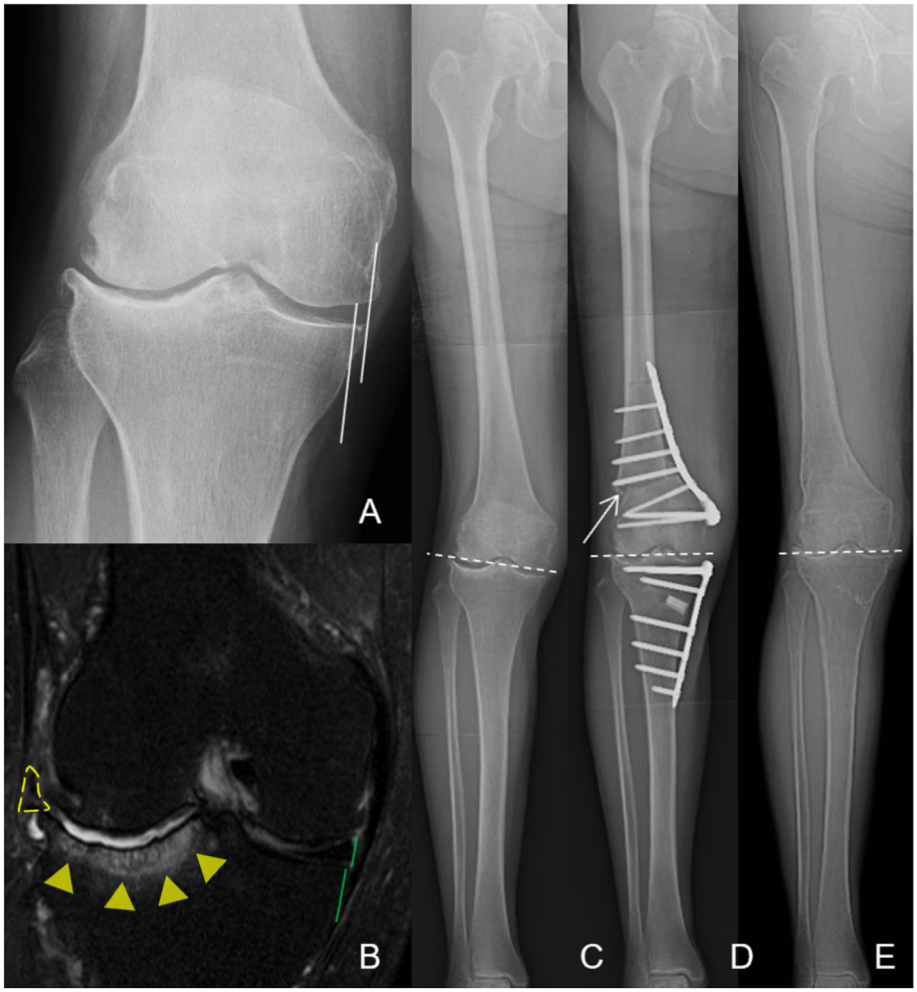

Fig. 2. Case 1: A 69-year-old woman who played competitive Naginata (long-handled sword).
A. Anteroposterior standing radiograph showing medial slip of the femur (white lines), B. Coronal view on T2-weighted fat suppression magnetic resonance imaging showing the complete exclusion of the lateral meniscus (triangle formed by the yellow dashed line). Mild medial meniscal extrusion is also seen (green lines). Bone marrow edema extends from the top of the lateral tibial eminence to the lateral edge of the lateral tibial plateau (yellow triangles), C. The preoperative hip-knee-ankle (HKA) angle, joint line obliquity (JLO; white dashed arrow), mechanical distal femoral angle (mLDFA), and mechanical medial proximal tibial angle (mMPTA) were 2°, 7°, 84°, and 83°, respectively, D. At the 6-month follow-up, despite the lack of change in the HKA angle compared with the preoperative angle, JLO (white dashed arrow), mLDFA, and mMPTA were corrected to 0°, 91° and 90°, respectively. Owing to a displaced hinge fracture (white arrow), the osteotomy site did not fuse, E. All corrected angles and the horizontalized joint line (white dashed line) were well preserved at the 5-year follow-up. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

with type II-aligned osteoarthritis who desire RTS.

2. Materials and methods

2.1. Inclusion criteria

FVTVO for CPAK type II-aligned knee osteoarthritis was considered for active patients who satisfied the following criteria: 1) JLO >5°; 2) mechanical medial proximal tibial angle (mMPTA)[20] < 87°; 3) mechanical lateral distal femoral angle (mLDFA) [20] < 87°; 4) three of the four theoretically possible osteoarthritis patterns mentioned in the introduction confirmed on coronal magnetic resonance images (Figs. 2–4); 5) flexion contracture <10°; and 6) Kellgren–Lawrence osteoarthritis grade 1–3. Among 10 patients who underwent FVTVO from 2014 to 2020, only those who met the following criteria were included in this study: 1) patients eager to RTS; 2) patients who were participating in a sports activity, with a Tegner activity scale[21] score ≥5 immediately before being affected by knee osteoarthritis; and 3) patients who completed at least 1 year of follow-up.

2.2. Surgical procedure

For the femur, biplanar medial closed wedge DFO[9] was chosen in all cases, and a lateral opening DFO was not performed to prevent complications.[22] For the tibia, our first choice was OWHTO using a pes-preserving technique,[3] and when the patient had moderate to severe patellofemoral osteoarthritis and/or flexion contracture ≥5°, hybrid CWHTO (HCWHTO) [5-7] was indicated. Our target mMPTA and hip-knee-ankle (HKA) angle were set at 90° and −2° to 2° for cases whose lateral compartment was mainly affected. When the medial osteoarthritis/cartilage defect was more than that in the lateral compartment, the mMPTA and HKA angle were set at 91°–93° and 1°–3°, respectively. Neutral alignment for lateral compartmental knee osteoarthritis appeared insufficient for decompression of the affected compartment. However, as the actual center of gravity is located close to the center of the body, which is medial to the center of the hip, the force transferred by the medial compartment was usually greater than that transferred by the lateral compartment in neutral-aligned knees.[23] This is why we aimed for neutral and valgus correction for lateral and medial

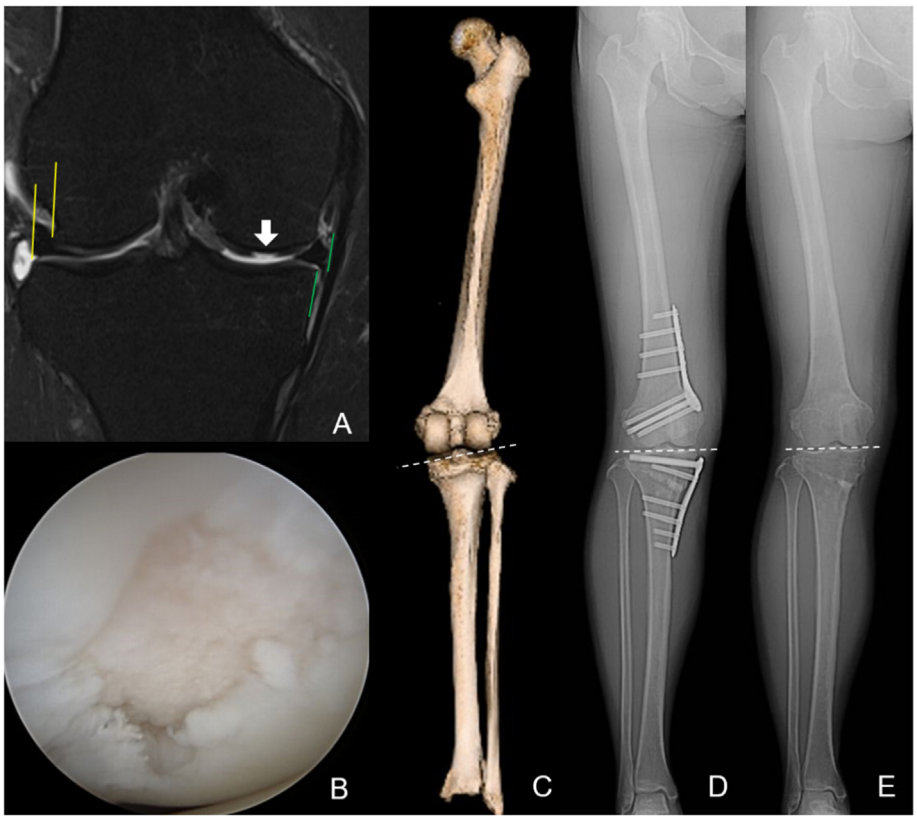

Fig. 3. Case 2: A 46-year-old woman who frequently climbed mountains higher than 3000 m above sea level.
A. Coronal view on T2-weighted fat suppression magnetic resonance imaging showing lateral meniscal extrusion from the lateral femoral condyle (yellow lines) in addition to medial meniscal extrusion (green lines). A large cartilage defect is visible on the medial femoral condyle (white arrow), B. The cartilage defect was confirmed on arthroscopy during osteotomy, C. Posteroanterior three-dimensional computed tomography (3D-CT) view of the whole leg showing the medial and lateral condyles. Although there are multiple possible 3D-CT views, the true posteroanterior view should be chosen. The true view shows the medial and lateral condyles with no obliquity. Using this view, the accurate value of each angle can be measured. The preoperative hip-knee-ankle angle (HKA), joint line obliquity (JLO; white dashed arrow), mechanical distal femoral angle (mLDFA), and mechanical medial proximal tibial angle (mMPTA) were 3°, 7°, 83°, and 84°, respectively, D. At the 6-month follow-up, JLO (white dashed arrow), mLDFA, and mMPTA were corrected to −3°, 90°, and 93°, respectively. The HKA was unchanged (3°), and bone union was complete, E. All corrected angles and the JLO (white dashed line) were well-preserved at the 2-year follow-up. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

compartmental osteoarthritis, respectively.

2.3. Postoperative rehabilitation

Range of motion exercises began on the first postoperative day and progressed gradually as tolerated. Full weight-bearing began 6 weeks after surgery. After confirming bone union of the anterior flange and the hinge, jogging was allowed at 3 months. RTS was allowed gradually 6–12 months postoperatively, and was allowed without restrictions after 1 year. This protocol was modified if an unstable hinge fracture was confirmed.

2.4. Assessment

The Japanese Orthopaedic Association (JOA) score[24] and range of knee flexion were assessed preoperatively and at the final follow-up after FVTVO. In addition to the types of sports activity, the level of the sports activity was examined using the Tegner activity scale presymptom, preoperatively, and at the final follow-up after FVTVO. The duration between FVTVO and returning to pre-symptom sports performance level was also recorded.

Radiological evaluation comprised anteroposterior and lateral views of the knee and a full-length anteroposterior view of the leg preoperatively, 6 months postoperatively, and at the final follow-up. The HKA angle, JLO, mLDFA, mMPTA, and lateral tibial subluxation were measured using the full-length anteroposterior radiographic view. The HKA angle was defined as the angle between the femoral and tibial mechanical axes in the anteroposterior view, with varus angles expressed as negative and valgus angles as positive. JLO was defined as the obliquity relative to the floor in the double-leg stance,[18] with laterally- and medially-tilted angles expressed as negative and positive, respectively. Lateral tibial subluxation was defined as the distance between the apex of the intercondylar notch and the extension of the tibial mechanical axis, in accordance with a study by Nam et al.[25] Using coronal views on T2-weighted fat suppression magnetic resonance imaging, meniscal extrusions, osteoarthritic change, and/or bone marrow edema in the lateral aspect of the tibial spine were observed. The values for mLDFA and mMPTA are presented in the figure legends (Figs. 2–4).

3. Results

Three cases (one man and two women) met the inclusion criteria, and all cases had returned to their presymptom sports activity levels by the final follow-up. The follow-up period in case 1, 2, and 3 was 8, 3.5, and 2 years, respectively. The preoperative/6-month/final follow-up HKA angles were 2°/2°/2°, 3°/3°/3°, and 2°/−1°/−1°, respectively, and JLOs were 7°/0°/0°, 7°/−3°/−3°, and 6°/0°/0°, respectively. Lateral tibial subluxation at each follow-up

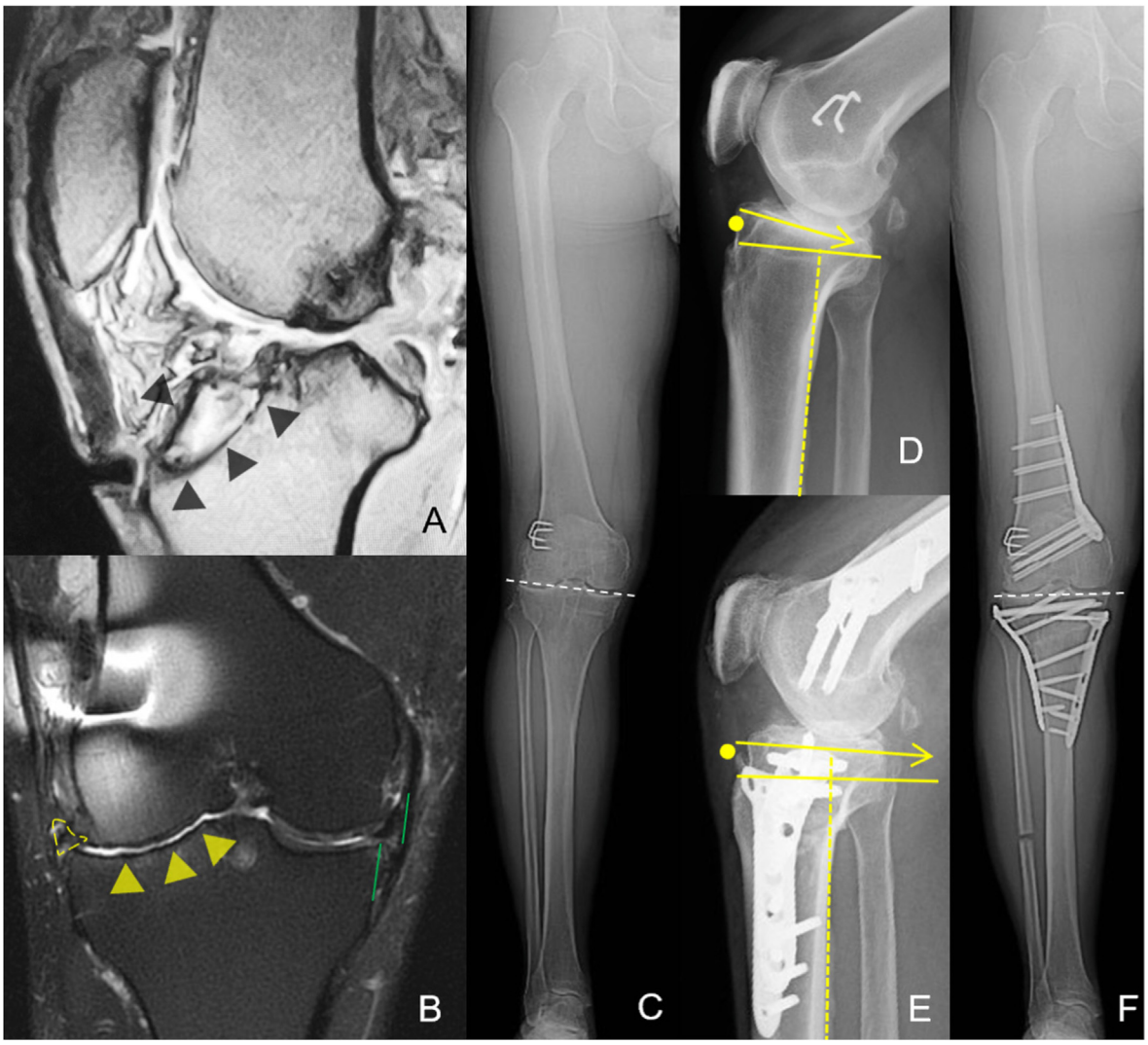

Fig. 4. Case 3: A 57-year-old man who participated in competitive alpine skiing at the national level
A. Magnetic resonance (MR) image, sagittal view, showing the complete absorption of the previously reconstructed anterior cruciate ligament with tibial bone tunnel expansion (black triangles). The tibia is anteriorly translated, B. Lateral meniscal extrusion from the lateral femoral condyle (triangle formed by the yellow dashed line) and medial meniscal extrusion (green lines) are visible on the coronal view of the T2-weighted fat suppression MR image. The lateral cartilage surfaces are irregular from the top of the lateral eminence to the lateral edge of the lateral tibial plateau (yellow triangles), C. The preoperative hip-knee-ankle angle (HKA), joint line obliquity (JLO; white dashed arrow), mechanical distal femoral angle (mLDFA), and mechanical medial proximal tibial angle (mMPTA) were 2°, 6°, 86°, and 85°, respectively, D. Preoperative lateral radiograph showing 12° of posterior tibial slope (PTS). PTS (yellow circle) was defined as the angle between the medial joint line (yellow arrow) and a perpendicular line (yellow line) to the posterior cortex (yellow dashed line), E. PTS (yellow circle) decreased to 2° after osteotomy, F. At the 6-month follow-up, HKA, JLO (white dashed arrow), mLDFA, and mMPTA were corrected to −1°, 0°, 90°, and 90°, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

was 5 mm/1 mm/1 mm, 6 mm/3 mm/3 mm, and 5 mm/0 mm/0 mm, respectively. These results indicated that the CPAK classification for all three cases was converted from type II to type V as planned, and lateral tibial subluxations were reduced by FVTVO.

3.1. Case details

A 69-year-old woman who had been participating in competitive Naginata, namely Japanese long-handled sword (Tegner scale 6), presented with progressive knee pain. When she visited our hospital, her Tegner scale and JOA scores were 1 and 70 points, respectively, and the knee range of flexion was 135°. X-rays revealed CPAK type II-aligned lateral osteoarthritis (Fig. 2A–C). She was eager to compete in Naginata again, and FVTVO was chosen based on the deformity analysis (Fig. 2D). A polyaxial locking plate designed for the proximal tibia was used[26] in the femur because a DFO-specific plate was not available. We adopted a supracondylar hinge,[27] which resulted in a delayed union with a displaced hinge fracture. OWHTO using TomoFix (Synthes GmbH; Solothurn, Switzerland) was performed for the tibia. Approximately 3 years was required for RTS at the presymptom level owing to the delayed union. The patient was satisfied with the 5-year results (Fig. 2E; Tegner scale/JOA score/flexion range = 6/90/135°, respectively).

A 46-year-old woman who climbed mountains as high as 3000 m above sea level (Tegner scale 5) started to experience difficulties in mountain climbing owing to right medial knee pain. Tegner scale and the JOA score were 2 and 65 points, respectively, and the knee range of flexion was 150° at her first visit. Knee valgus was mild (CPAK type II; HKA angle = 3°; Fig. 3C); however, there was a large cartilage defect on the medial femoral condyle (Fig. 3A and B). Because the patient wished to return to mountain climbing, FVTVO was performed without changing the coronal varus/valgus

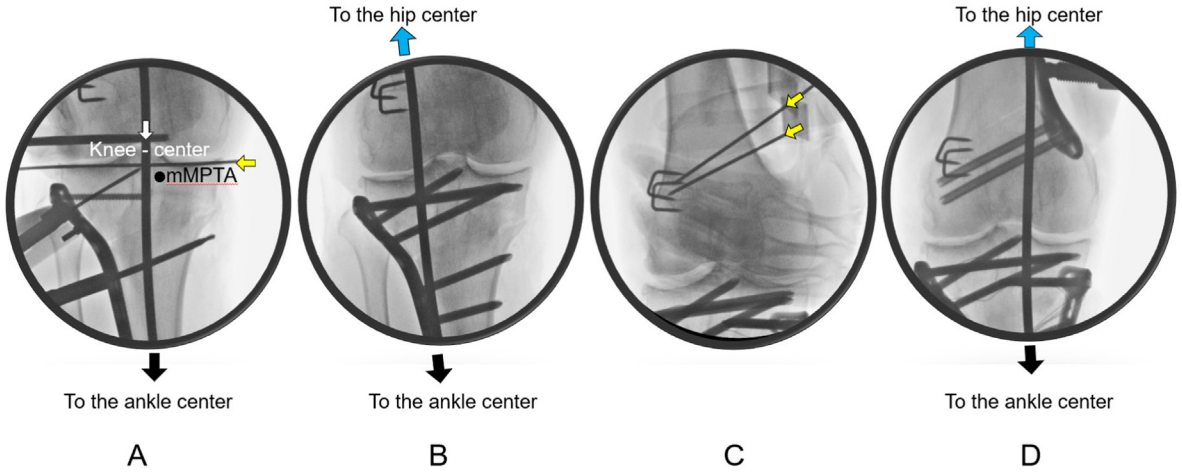

Fig. 5. Surgical procedure for femoral-varus tibial-valgus osteotomy (FVTVO). Intraoperative fluoroscopic views of Case 3 are shown.
A. High tibial osteotomy (HTO) was performed prior to distal femoral osteotomy (DFO). After temporary fixation for hybrid closed wedge HTO (HCWHTO), the mechanical medial proximal tibial angle (mMPTA) was measured using an alignment rod. The rod was grasped with a Kocher clamp at the knee center (white arrow) and the ankle center (black arrow). The mMPTA (black circle) was confirmed as 90° (the medial angle between the joint line [yellow arrow] and the rod), B. Locking screws for the lateral plate were then inserted. The mechanical axis of the whole leg, which was formed by the alignment rod connecting the hip center (blue arrow) and the ankle center (black arrow), was checked on the monitor, and the image data were sent to the picture archiving and communication system (PACS). The lead surgeon then stopped the surgery and devised a plan for DFO using the PACS, C. In accordance with the plan, two Kirschner wires (yellow arrows) as guides for medial closed wedge DFO (MCWDFO) were inserted, D. After wedge closure, a locking plate was temporarily fixed with a compression hook device, and the final alignment was fine-tuned with reference to the alignment rod that connected the hip center (blue arrow) and the ankle center (black arrow). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

alignment (Fig. 3D). Fourteen months after surgery, she successfully returned to mountain climbing at the same level as before being affected by the cartilage defect. The Tegner scale and JOA scores, and flexion range at the 2-year follow-up were 5, 100, and 150°, respectively (Fig. 3E).

A 57-year-old male competitive alpine skier (Tegner scale 7) who underwent anterior cruciate ligament (ACL) reconstruction of the right knee at 22 years of age presented with a chief complaint of knee pain during skiing. The reconstructed ACL had been absorbed (Fig. 4A) at presentation, with lateral osteoarthritis accompanied by a concave lateral tibial plateau (Fig. 4B). Because of the fixed anterior tibial translation owing to the progressed osteoarthritic changes, the results of the anterior drawer test, Lachman's test, and the pivot shift test were negative, and there was no complaint regarding knee instability. The preoperative Tegner scale and JOA scores and the knee flexion range were 3, 70, and 120°, respectively. Whole-leg X-rays demonstrated CPAK type II-aligned lateral knee osteoarthritis (Fig. 4C), and FVTVO was planned to return the patient to skiing at a competitive level. Posterior slope-decreasing dual-plating (TomoFix, small version, for the medial side and TomoFix PLT for the lateral side; Synthes GmbH) HCWHTO[7] was chosen for the tibial osteotomy to decrease the shear stress created by the anterior tibial translation.[28] Owing to the slope-decreasing HCWHTO,[7] the 10° of preoperative flexion contracture was also eliminated, and full extension was obtained (Fig. 4D and E and 5). Biplanar DFO using a TriS-MDFO plate (Olympus Terumo Biomaterials, Tokyo, Japan) was performed for the femur (Figs. 4F and 5). The patient fully returned to skiing 12 months after FVTVO, before plate removal. The Tegner scale and JOA scores and the knee flexion range at the final follow-up (1.5 years) were 7, 90, and 120°, respectively.

4. Discussion

The relationship between JLO and osteoarthritis progression has recently attracted attention. Nakamura et al.[29] proposed that the tensile stress driven by the medially-slipped femur with medially-tilted JLO could cause meniscal hoop disruption. Wang et al.[19] proved that excessive JLO alteration may cause abnormal tibiofemoral joint articulation and chondral or meniscal loading, using a cadaveric study. Shoji et al.[30] reported that cases with medially-tilted JLO >15° had poor results after medial CWHTO for valgus deformity. Nakayama et al.[31], using a three-dimensional finite element model analysis, proved that JLO ≥5° may induce detrimental stress to the articular cartilage. Therefore, the crucial key to successful AKO is to create a horizontal joint line with sufficient correction of the varus/valgus deformity to shift the weight-bearing line from the affected compartment to the unaffected compartment. However, no study has elucidated the solitary effect of joint line-horizontalization osteotomy without changing the coronal varus/valgus alignment.

Another key to success with FVTVO is implementing the appropriate surgical indication. As mentioned, the indication is a medially tilted joint line with osteoarthritis of the lateral aspect of the tibial spine in knees that have a valgus femur and varus tibia. However, there may be limitations associated with this indication. First, cases with a JLO ≥10° would not be recommended for FVTVO because such cases require a large amount of medial closing at the distal femur, which may induce an unstable lateral hinge fracture. Second, severe lateral tibial subluxation with a “single tibial spine” owing to excessive abrasion of the lateral tibial spine (Fig. 1D) may be a contraindication. As the subluxation in these cases cannot be reduced, TKA would provide better results compared with FVTVO. Additionally, when HCWHTO is performed for the tibia, flexion contracture can be eliminated by reducing the tibial posterior slope.[7)] However, in cases with flexion contracture ≥10°, this procedure may produce an anterior tibial slope in the sagittal plane, which may induce femoral anterior slip during walking.

Our results support the initial hypothesis that FVTVO, even without coronal alignment correction, enabled RTS equal to that obtained with OWHTO.[4] The unrestricted return to high- or low-impact sports may be owing to the beneficial effect of the joint line horizontalization, which decreases shearing stress during sports activities. Lateral unicompartmental knee arthroplasty appears to be another possible option; however, the oblique joint makes it difficult to install the unicompartmental components

appropriately. Additionally, lateral unicompartmental knee arthroplasty is not indicated in cases with medial hoop disruption owing to the JLO; thus, TKA could be the only prosthetic solution for osteoarthritis with severe JLO. However, high-impact sports activities are not recommended after TKA because of the presence of large intraarticular prostheses[32] and the risk of periprosthetic fracture.[16] Because we routinely remove the plates after bone union after performing FVTVO, the risk of implant-related complications, such as fracture around the plate is eliminated. Therefore, non-prosthetic joint line horizontalization by FVTVO for knee osteoarthritis with severe JLO may have substantial benefits that enable safe RTS.

Additional procedures, such as meniscal root repair, meniscal centralization, osteochondral autograft, and autologous chondrocyte implantation, could further improve the effects of FVTVO. However, as FVTVO is currently an unproven technique, a high number of combined surgeries is not recommended. This is a possible limitation of this study, in addition to the small number of cases and the short follow-up period.

5. Conclusion

FVTVO for neutral-aligned knee osteoarthritis with severe JLO achieved highly satisfactory clinical results, including RTS.

Declaration of interest statement

Dr Ryuichi Nakamura is a consultant with Olympus Terumo Biomaterials. All other authors have no conflicts of interest relevant to this article.

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