Original Article

Anteromedial plating without filling the gap in open wedge high tibial osteotomy may increase the risk of screw breakage, which can be reduced by medial plating and bone-substitute insertion

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A B S T R A C T

Background: Open wedge high tibial osteotomy (OWHTO) brings new complications such as screw breakages with or without correction loss and time-dependent increased posterior tibial slopes (PTS) due to the opening gap. For preventive purposes, we changed our OWHTO procedure from anteromedial plating without filling the gap (non-grafted group, n = 40, 2009–2012) to medial plating with bone-substitute insertion (grafted group, n = 45, 2012–2015). The objectives of this study were to evaluate the complication patterns and the effects of the modifications.

Methods: Patients undergoing OWHTO with TomoFix plates were included in this retrospective study. Demographics, clinical outcomes (flexion range and Japanese Orthopaedic Association score) and radiological outcomes (femorotibial angle) were assessed in both groups pre-operatively and 2-years postoperatively. The plate installation angle [PIA] and screw insertion depth [SID] were measured on computed tomographic slices at 6 months. PIA/SID was defined as the angle between the tibial anteroposterior axis and plate–width axis/the distance between the proximal screw tip and the proximal tibiofibular joint. The non-grafted group was further divided into complication and non-complication subgroups. Screw breakages were assessed during plate removal (1.5–2.5 years postoperatively).

Results: There were no differences in baseline characteristics or radiological/clinical outcomes between the non-grafted and grafted groups. There were 0 and 11 complications in the grafted and non-grafted groups, respectively. Complications included 7 screw breakages, 4 correction losses, and 5 time-dependent increased PTS with some overlaps. PIA and SID were significantly lower (p < 0.001) and higher (p < 0.001), respectively, in the grafted group and significantly lower (p = 0.018) and higher (p = 0.040), respectively, in the non-complication subgroup within the non-grafted group. The cutoff value of PIA for complications was calculated at 48.0°.

Conclusions: Medial plating OWHTO (PIA<48°) using bone-substitute with deeper screw insertion re-inforces the opening gap for better angular stability compared with anteromedial plating without bone-substitute.

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1. Introduction

Since the introduction of locking plates specifically designed for open wedge high tibial osteotomy (OWHTO), such as the TomoFix Medial High Tibial Plate (Synthes GmbH; Solothurn, Switzerland), the clinical outcomes of OWHTO have been significantly improved [1–3]. The improved clinical results may be attributed to the characteristic symmetry of the TomoFix, which provides greater flexibility (Fig. 1), and the pure titanium long plate. However, some new complications that did not exist for closed wedge high tibial osteotomy have arisen in OWHTO. The most common intra- and post-operative OWHTO-specific complications are lateral hinge

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fracture [4–6] and delayed gap healing [7], respectively, as a result of the inherent nature of the medial opening gap [8]. Although screw breakage with and without correction loss has been considered a less common OWHTO-specific complication [8], some undetected occult screw breakages may occur [9] because the plate is not routinely removed in European countries. In Asian individuals who underwent OWHTO with TomoFix, the plate was always removed [9,10] because it was too bulky to be left permanently in place. For this reason, we removed the plate in all OWHTO cases, which provided us with many more opportunities to inspect cases with screw breakages (Fig. 2) and/or increased posterior tibial slopes over time (Fig. 3). The increased posterior tibial slope over time is a lesser-known complication [11] compared with the intraoperative increased slope [12]. However, careful radiological evaluation after plate removal highlighted the importance of time-dependent slope change.

When we began using OWHTO with a locking plate, we did not insert any bone-substitutes (non-grafted group) according to our hypothesis that the stability of the locking system is enough for early full weight-bearing. Despite the controversy about the requirement for gap-fillers [13,14], we started to use bone substitutes (grafted group) to prevent complications after some experience of screw breakage and/or increased posterior tibial slope over time. Furthermore, some modifications of the plate installation (Figs. 4–7) were made simultaneously with the commencement of bone-substitution insertion.

The first objective of this study was to compare the rate of delayed onset bone/implant-related complications such as screw breakage with and without correction loss and time-dependent increase of the posterior tibial slope between grafted and non-grafted groups. The second objective was to clarify the effect of the plate installation angle and the screw insertion depth on the rate of bone/implant-related complications.

2. Materials and methods

2.1. Cohorts

This retrospective cohort study was approved by the institutional review board of the authors’ affiliated institutions (no. 2020-2) and carried out in accordance with the Declaration of Helsinki. Written informed consent for this research was not obtained because of the retrospective design. The study population consisted of patients meeting the eligibility criteria [5] and who underwent OWHTO for medial compartment knee osteoarthritis. The cohorts

Fig. 1. The TomoFix plate is symmetric about its width. The flexibility of the plate is highest in the plane formed by the plate–length axis and the plate–thickness axis.

Fig. 2. A 68-year-old female with multiple screw breakages complicated by a correction loss (Case 10). (A) Full-length view at 1 month reveals a mechanical medial proximal tibial angle (mMPTA) of 92°. Joint line (white line), mechanical axis (white dashed line). (B) Full-length anteroposterior view 2 years after surgery. A correction loss has occurred because of the change in the mMPTA (decreased to 88°). Screw breakage could not be radiologically detected. (C) The removed plate. Three out of four proximal screws (B, C, and D) were broken at the head–shaft interface.

Fig. 3. A 69-year-old male with time-dependent increased posterior tibial slope (Case 1). The white circles indicate the posterior tibial slope. The slope was 3° at 1 month (A) and 8° at 2 years (B). Medial joint line (white line), the perpendicular line (white arrow) to the posterior cortex (white dashed line).
were (1) OWHTOs treated between June 2009 and May 2012 without bone-substitute insertion (non-grafted group, i.e., pre-modification), and (2) OWHTOs treated between June 2012 and September 2015 with bone-substitute insertion (grafted group, i.e., post-modification).

2.2. Transition of indication and/or surgical procedure

During the study period, in addition to whether bone-substitute was used, there were several changes in our OWHTO indications and/or surgical procedure. In the early stages of the consecutive series, an opening distance <15 mm was considered to be an indication for OWHTO [5], while in the latter stages, the opening distance criterion was modified from <15 mm to <12 mm to prevent unstable lateral hinge fractures [4,5]. Furthermore, with the improvement in the accuracy of early stage diagnosis of osteoarthritis induced by meniscal hoop disruption [15], an increased number of patients underwent a minor correction of <8 mm in the latter stage of this series. In terms of plate fixation, we performed OWHTOs using several types of locking plates: TomoFix (original, small, or new-generation standard versions) or TriS (Olympus Terumo Biomaterials, Tokyo, Japan) [16]. Although all plates were removed after a period of approximately 2 years, the number of removals occurring earlier than 1.5 years increased after the introduction of the bone-substitute.

2.3. Exclusion and inclusion criteria of this study

The patients who underwent OWHTO in combination with other surgeries (ligament reconstruction, osteochondral graft, or autologous chondrocyte implantation) and OWHTO with unstable lateral hinge fracture (Takeuchi type II or III) [4] were first excluded because these conditions have some potential adverse effect on the results. Furthermore, to compare both groups under the same conditions, only the cases that met the following inclusion criteria were included: 1) OWHTO was performed by a single surgeon, 2) small size TomoFix was used, 3) time to plate removal was between 1.5 and 2.5 years, and 4) opening distance was 8–12 mm. A flow-chart illustrating the patient selection process is depicted in Fig. 8. The follow-up rate of the selected patients was 100%.

2.4. Common surgical procedures/postoperative rehabilitation in both groups

In both groups, the target post-operative femorotibial angle [17] was 170° [10,14], which corresponds to 60%–70% in the weight-bearing line percentage [14]. Through a reversed curved oblique incision, a biplanar OWHTO was performed using a pes-preserving technique [16] with complete release of the superficial medial collateral ligament (MCL). The same rehabilitation was applied to both groups. Patients began their range of motion exercises within 2 days of their operation. Partial and full weight-bearing began 1 and 3 weeks after surgery, respectively.

2.5. Differences in surgical procedure between non-grafted and grafted groups

In the non-grafted group [5], a bone spreader was inserted into the posterior gap after the osteotomy, and the gap was opened to the distance determined by the target post-operative alignment. The MCL was released and reflected posteriorly, and the plate was installed on the anteromedial aspect (Figs. 4A, 6A and 7A) [1] without repairing the MCL.

In the grafted group [16], we used a bone-substitute block made of β-tricalcium phosphate (OSferion 60, Olympus Terumo Biomaterials, Tokyo, Japan) [18], which can be easily cut into appropriately sized wedges [14]. Two bone-substitute wedges—posterior and anterior—were cut beforehand from the block to fit the target opening gap (Figs. 4B, 6B and 7B). After widening the posterior gap to the target distance, an additional bone spreader was inserted into the anterior gap to maintain the appropriate distance. The posterior spreader was then removed, and the posterior wedge was inserted. The anterior wedge was inserted after removing the anterior spreader. The MCL was returned into its original position beneath the pes anserinus and repaired (Fig. 6B). A TomoFix plate was installed on the medial aspect of the proximal tibia [19], with the proximal screws pointing toward the proximal tibiofibular joint (PTFJ) (Figs. 4B, 5 and 6B and 7B).

2.6. Radiological examinations

Radiological evaluations comprised full-length anteroposterior views of the leg (pre- OWHTO, 1 month and 2 years post-OWHTO),
anteroposterior/lateral views of the knee (pre-OWHTO, 1, 3, and 6 months, and 1, 1.5, and 2 years post-OWHTO), and computed tomography (CT) scans at 6 months post-OWHTO.

The femorotibial angle [17] and mechanical medial proximal tibial angle [20] were measured on the full-length radiograph and the posterior tibial slope was measured on the lateral view. The posterior tibial slope is defined as the angle between the medial joint line and the perpendicular line to the posterior cortex of the tibia because the view of the anterior cortex was impeded by the plate in some instances [11]. Correction loss was defined as a reduction in the mechanical medial proximal tibial angle at 2 years compared with that at 1 month /C21/C23/C14/C13/. Time-dependent increased posterior tibial slope was defined as an increased slope at 2 years compared with that at 1 month ≥ 3°.

On the CT scans, using superimposed views of axial slices at 6 months, the plate installation angle and screw insertion depth were measured (Figs. 5 and 6). The plate installation angle was defined as the angle between the tibial anteroposterior axis according to Akagi et al. [21] and the plate-width axis (Figs. 5 and 6). The screw insertion depth, with reference to the PTFJ, was defined as the distance between the lateral tip of the screw and the margin of the PTFJ (Figs. 5 and 6). When the screws were inserted beyond or short of the PTFJ, the values were defined as positive and negative, respectively (Figs. 5 and 6).

2.7. Assessment

We collected characteristics of the cases including sex, age, body mass index, opening distance, and time from OWHTO to plate removal. Clinical outcomes were assessed by the Japanese Orthopaedic Association (JOA) score and the knee flexion range pre-OWHTO and 2 years post-OWHTO. Radiological data consisted of the femorotibial angle, the posterior tibial slope, the plate installation angle, and the screw insertion depth. Among the three types of bone/implant–related complications, correction loss and time-dependent increase in the posterior tibial slope were assessed at the designated radiological follow-up period mentioned above, and screw breakages were recorded at the plate-removing surgery independently of the radiological follow-up. The anterior, middle, and posterior screws of the plate were defined as A, B, and C, respectively, and the screw in the second row was defined as D (Fig. 2).

2.8. Statistical analysis

We compared demographic data, clinical data, radiological data, and complications between non-grafted and grafted groups. Chi-square tests and Fisher exact tests were applied to compare sex and the rate of complications. Student’s t-tests, Mann–Whitney U tests, and Welch t-tests were used to compare the other values between groups. The non-grafted group was further divided into no bone/implant-related complications (non-complication group) and those with bone/implant-related complications (complication group) to reveal the solitary effect of the plate installation without the possible effect of the bone-substitute. The same evaluation items as in the non-grafted and grafted groups were compared between the non-complication and complication groups. Spearman’s rank correlations between the plate installation angle and the screw insertion depth were calculated. Paired t-tests and Wilcoxon signed-rank tests were used to compare pre-operative and 2-year follow-up JOA scores, knee flexion ranges, and femorotibial angles. A p-value of <0.05 was considered to be statistically significant.

Logistic regression analysis was performed with the presence or absence of complications as the dependent variable, and the plate installation angle and screw insertion depth as the independent variables. A receiver-operating characteristic (ROC) curve and cutoff value were calculated after logistic regression analysis on
intraoperative factors (plate installation angle and screw insertion depth). SPSS Statistics version 24 (IBM Corp., Armonk, New York) and R version 4.1.0 were used as the analysis software. A priori power analysis was conducted (G*power, version 3.1.7) based on a medium effect size, and a post hoc power analysis was performed on the results of statistical analysis in each phase.

3. Results

Among 284 OWHTOs, 85 knees met the eligibility criteria (Fig. 8). The non-grafted and grafted groups comprised 40 and 45 cases, respectively (Table 1). Patients in the non-grafted group were not characteristically different from those in the grafted group; sex, age, body mass index, opening distance, and time to plate removal did not differ significantly between the groups (Table 1). Clinical and radiological parameters did not differ significantly between groups either pre-operatively or at 2 years (Table 2). In both groups, parameters were corrected by OWHTO, which is demonstrated by the significant differences between before OWHTO and 2 years after OWHTO (p < 0.001) (Table 2).

The plate installation angle was significantly lower (p < 0.001) and the screw insertion depth was significantly higher (p < 0.001) in the grafted group (Table 2). When the plate installation angle and the screw insertion depth were plotted, there was a strong linear relationship between them (R² = 0.537, p < 0.001) (Fig. 9).

There were no complications in the grafted group, and the complication rate was significantly higher in the non-grafted group than that in the grafted group (p < 0.001) (Table 2). Post hoc power analysis for this outcome (alpha value of 0.05, Cohen’s d of 2.04 in screw insertion depth, and total sample size of 85 for a 2-tailed hypothesis) demonstrated an observed power of 100%.

In the non-grafted group, there were 11 cases with bone/implant-related complications (Table 3) and Case 9 was converted to total knee arthroplasty. The complications consisted of 7 screw breakages, 4 correction losses, and 5 time-dependent posterior tibial slope increases with some overlaps (Table 3). All screw breakages occurred at the head/shaft interface (Fig. 2C). Thirteen screws were broken, with 0, 4, 6, and 3 breakages occurring in A-, B-, C-, and D-screws, respectively (Table 3). Three out of four correction loss cases had multiple broken screws, while four out of five cases with increased posterior tibial slopes had no broken screws (Table 3). When the non-grafted group was divided into non-complication and complication groups, demographics, pre-operative clinical measures, and pre-operative radiological measures did not differ significantly between groups (Tables 4 and 5); however, the femorotibial angle at 2 years was significantly larger for the complication group because there were some correction losses (Table 5). Nevertheless, the JOA score and knee flexion range at 2 years did not differ significantly between the non-complication and complication groups (Table 5).

The plate installation angle was significantly lower (p = 0.018) and the screw insertion depth was significantly higher (p = 0.040) in the non-complication group than in the complication group (Table 5). Logistic regression analysis identified the plate installation angle as a possible factor (standardized regression coefficient β = 0.302, odds: 1.18). In the analysis of the ROC curve, the cutoff value of the plate installation angle was 48.0, area under curve was 0.699, sensitivity was 0.817, and specificity was 0.621 (Fig. 10).
hoc power analysis between these two groups (alpha value of 0.05, Cohen’s d of 1.13 in the plate installation angle, and total sample size of 40) demonstrated an observed power of 86%.

4. Discussion

Because there were no systematic differences between the baseline characteristics of the non-grafted group and those of the grafted group (Tables 1 and 2), we consider it reasonable to compare outcomes between the groups. The results of comparison under the same conditions revealed numerous bone/implant-related complications that occurred only in the non-grafted group. Therefore, our initial hypothesis that the stability of the TomoFix is enough for early full weight-bearing without filling the gap was rejected.

However, simultaneous modification of the plate installation could be a possible complication factor that should be considered. The significantly smaller plate installation angle in the grafted group (Table 2); that is, screw insertion normal to the tibial anteroposterior axis (Figs. 4–6), indicated that, with the modification, the plate was installed on the more medial aspect rather than the anteromedial aspect of the tibia. In addition to the intentional medial plating, plate fixation after removing the spreader made medial plating technically easier (Fig. 6). The significantly larger screw insertion depth in the grafted group (Table 2) indicated that, with the modification, the proximal screws were aimed toward the PTFJ. The strong linear relationship between the plate installation angle and the screw insertion depth (Fig. 9) meant that more medial plating enabled deeper screw insertion towards the PTFJ. No bone/implant-related complications were found in the grafted group (Table 2), which suggests that the modified surgical procedure may reduce the chance of complications.

In the non-grafted group, of the three bone/implant-related complications, the most frequent was screw breakage (Table 3). No screw breakage was caused by trauma; the breakages appeared to be caused by stress beyond the long-term durability of the screws. Interestingly, all cases except one included the posterior screw (Table 3), which suggests that the posterior part of the plate might be exposed to more stress than the other parts of the plate.

Takeuchi et al. [19] reported that the sagittal weight-bearing line moves posteriorly with knee flexion during walking, and

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Fig. 8. Flowchart illustrating the patient selection process. ACL, anterior cruciate ligament. ACI, autologous chondrocyte implantation.
Table 1
Comparisons between non-grafted and grafted group characteristics.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Non-grafted group</th>
<th>Grafted group</th>
<th>Between-group p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>40 n or mean (SD, range)</td>
<td>45 n or mean (SD, range)</td>
<td>N/A</td>
</tr>
<tr>
<td>Sex (male/female)</td>
<td>10/30</td>
<td>15/30</td>
<td>0.352</td>
</tr>
<tr>
<td>Age</td>
<td>62.2 (SD 8.1, 42 to 74)</td>
<td>65.3 (SD 8.4, 46 to 80)</td>
<td>0.082</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>24.2 (SD 2.3, 20 to 30)</td>
<td>24.4 (SD 2.7, 20 to 32)</td>
<td>0.993</td>
</tr>
<tr>
<td>Opening distance (mm)</td>
<td>10.4 (SD 1.1, 8 to 12)</td>
<td>9.9 (SD 1.3, 8 to 12)</td>
<td>0.080</td>
</tr>
<tr>
<td>Time to plate removal (year)</td>
<td>2.0 (SD 0.1, 1.6 to 2.2)</td>
<td>1.9 (SD 0.2, 1.6 to 2.4)</td>
<td>0.092</td>
</tr>
</tbody>
</table>

The chi-square test was used to compare sex; the Student’s t-test was used to compare age, and the Mann–Whitney U-test was used to compare body mass index, opening distance, and time to plate removal between the non-grafted and grafted groups.

N/A, not applicable.

Table 2
Comparisons between non-grafted and grafted group outcomes and assessments.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Assessment</th>
<th>Non-grafted group mean (SD, range)</th>
<th>Comparison between assessment p value</th>
<th>Grafted group mean (SD, range)</th>
<th>Comparison between assessment p value</th>
<th>Between-group p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japanese Orthopaedic Association score</td>
<td>Pre-operative</td>
<td>69.5 (SD 12.2, 40 to 85)</td>
<td>&lt;0.001</td>
<td>69.2 (SD 10.6, 40 to 85)</td>
<td>&lt;0.001</td>
<td>0.785</td>
</tr>
<tr>
<td>Knee flexion range (°)</td>
<td>Pre-operative</td>
<td>91.8 (SD 8.4, 60 to 100)</td>
<td>&lt;0.001</td>
<td>93.6 (SD 5.5, 80 to 100)</td>
<td>&lt;0.001</td>
<td>0.501</td>
</tr>
<tr>
<td></td>
<td>Two years</td>
<td>133.3 (SD 13.9, 100 to 155)</td>
<td>&lt;0.001</td>
<td>138.0 (SD 10.5, 120 to 155)</td>
<td>&lt;0.001</td>
<td>0.164</td>
</tr>
<tr>
<td>Femorotibial angle (°)</td>
<td>Pre-operative</td>
<td>146.0 (SD 8.8, 125 to 155)</td>
<td>&lt;0.001</td>
<td>145.0 (SD 8.9, 130 to 155)</td>
<td>&lt;0.001</td>
<td>0.579</td>
</tr>
<tr>
<td></td>
<td>Two years</td>
<td>179.2 (SD 1.8, 174 to 182)</td>
<td>&lt;0.001</td>
<td>178.5 (SD 2.5, 172 to 184)</td>
<td>&lt;0.001</td>
<td>0.139</td>
</tr>
<tr>
<td>Plate installation angle (°)</td>
<td>6 months</td>
<td>170.9 (SD 2.0, 163 to 174)</td>
<td>171.1 (SD 3.0, 166 to 182)</td>
<td>0.585</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screw insertion depth (mm)</td>
<td>6 months</td>
<td>47.9 (SD 7.2, 25 to 63)</td>
<td>26.2 (SD 10.6, 4 to 47)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone/implant-related complications 1.5–2.5 years</td>
<td>11</td>
<td>4.3 (SD 4.2, −7 to 11)</td>
<td>0</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(at the time of plate removal)</td>
<td>0</td>
<td>0</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Paired t-tests and Wilcoxon signed-rank tests were used to compare pre-operative and 2-year follow-up values. Mann–Whitney U-tests and Welch t-tests were used to compare Japanese Orthopaedic Association score, knee flexion range, femorotibial angle, plate installation angle, and screw insertion depth between the non-grafted and grafted groups. The chi-square test was used to compare the rates of bone/implant-related complications.

Fig. 9. Relationship between screw insertion depth and the plate installation angle. The cutoff value of the plate installation angle for the risk of bone/implant-related complications is denoted by the dashed line.
Furthermore, because no complications occurred in cases with a positive screw insertion depth, insertion of the screw tip above the PTJ, which allows the fibula to work as a supporting strut [5,16], could be a sufficient condition. This interpretation corresponds to the suggestion by Takeuchi et al. [19] that the posterior stability of the osteotomy site might be weakened in the anteromedial position when TomoFix is used without a bone substitute. Thus, if long-term pendular micro-motion causes stress that surpasses screw durability, the posterior screw, with the largest arc, may experience breakage, while the anterior screw would be less affected (Fig. 4A). Breakage of the posterior screw may subsequently expose the middle and anterior screws to overload and result in further screw breakage.

Screw breakages seemed to occur prior to correction loss in the non-grafted group, the posterior-dominant stress during walking and the angular stability may decrease further. This interpretation corresponds to the suggestion by Takeuchi et al. [19] that the posterior stability of the osteotomy site might be weakened in the anteromedial position when TomoFix is used without a bone substitute. Thus, if long-term pendular micro-motion causes stress that surpasses screw durability, the posterior screw, with the largest arc, may experience breakage, while the anterior screw would be less affected (Fig. 4A). Breakage of the posterior screw may subsequently expose the middle and anterior screws to overload and result in further screw breakage.

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remaining three proximal screws may manage to support the medial side; however, with multiple screw breakages, the loss of medial support for the axial load is followed by correction loss.

The increased posterior tibial slope without screw breakage can be explained by the motion of lumbar spine. Mizuno et al. [23] reported that repetitive movement in the lumbar spine might cause loosening of the screw after pedicle screw fixation, which can be observed as a clear zone formation around the screws [24]. When the cancellous bone in the proximal part of the osteotomy succumbs to the effects of pendular micro-motion of the screw, increased posterior tibial slope instead of screw breakage may occur (Fig. 11).

In the grafted group, even though OWHTO generates medial cortex discontinuity from the opening gap, a strut is created that comprises the proximal cortex, bone-substitutes, and the distal cortex (Figs. 4B and 7B). Because the OSErion 60, with 60% porosity, used here can provide adequate strength to weight-bearing [18], the strut would reinforce the gap by reducing posterior sinking from the pendular micro-motion (Fig. 4). This continuity may redistribute weight-bearing to the strut from the TomoFix and improve the TomoFix’s durability (Figs. 4B and 7B), thus helping to reduce complications. In addition to the effect of the bone-substitute itself, facilitating the medial plating towards above-PTFE insertion (Fig. 7B) by modification may also assist in reducing complications.

Following the OWHTO modification, post-operative rehabilitation and lifestyle guidance was revised to minimize pendular micro-motion and is being investigated as an ongoing study. Walking exercises without bending the knee begin early after surgery. Passive flexion exercises and deep knee flexion, such as that experienced during Japanese-style sitting or weeding a garden in a squatting position, are allowed after bone union.

This study had some limitations. First, this was a retrospective study with a small sample size. Second, several modifications that could not be separated from each other were simultaneously performed. Therefore, it is difficult to understand how each modification—bone-substitute insertion, changes in the plate installation angle, or the screw insertion depth—contributed to the prevention of bone/implant–related complications.

In conclusion, anteromedial plating with a plate installation angle of >48° without filling the gap may increase the risk of bone/implant-related complications such as screw breakage, correction loss, and time-dependent increased posterior tibial slope. The complication risk can be reduced by medial plating with bone-substitute insertion.

IRB approval

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Authors’ contributions

Each author made substantial contributions to the following components of the project: conception, design, interpretation of data, drafting of the manuscript. All authors read and approved the final manuscript.

Declaration of competing interest

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

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