



Title	Effect of the Inverted V-Shaped Osteotomy on Patellofemoral Joint and Tibial Morphometry as Compared With the Media Opening Wedge High Tibial Osteotomy
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1 The effect of the inverted V-shaped osteotomy on the patellofemoral joint and tibial  
2 morphometry compared to the medial opening wedge high tibial osteotomy.

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25  
26 Footnotes

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29

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33 for supporting the medical devices to develop this osteotomy procedure.

34 **ABSTRACT**

35 **Background:** Recent studies have reported that medial opening wedge high tibial  
36 osteotomy (OW-HTO) induces patella baja, resulting in the degenerative change of the  
37 patellofemoral (PF) joint. The authors have developed an inverted V-shaped (iV) HTO,  
38 which is classified as a neutral wedge osteotomy.

39 **Hypothesis:** The study hypotheses were as follows: (1) The patellar height, the posterior  
40 tibial slope, and the tibial length will not change between pre- and post-operative  
41 evaluations after iV-HTO. (2) The lateral shift ratio of the patella and the distance between  
42 the tibial tubercle and the trochlear groove (TT-TG) may be significantly decreased after  
43 iV-HTO.

44 **Study Design:** Retrospective comparative study; Level of evidence, 3.

45 **Methods:** 191 patients (220 knees) who underwent HTO for medial osteoarthritis (OA)  
46 were enrolled retrospectively in this study. In the OW group, 107 knees underwent OW-  
47 HTO. In the iV group, 113 knees underwent iV-HTO. Clinical and radiological  
48 evaluations were performed before and at least 3 years after surgery.

49 **Results:** Postoperatively, the mean Caton-Deschamps ratio was significantly decreased  
50 ( $p < 0.0001$ ) from 0.95 to 0.79 in the OW group, while there were no significant changes  
51 in the iV group. The mean posterior tibial slope was significantly increased ( $p < 0.0001$ )

52 from 8.5° to 10.5° in the OW group, while there were no significant differences in the iV  
53 group. Although the entire leg length was significantly increased ( $p<0.0003$ ) after both  
54 groups, there were no significant differences in the tibial length between the pre- and post-  
55 operative periods in the iV group. Regarding the congruity of PF joint, the mean lateral  
56 shift ratio did not significantly change in the OW group, whereas it was significantly  
57 decreased ( $p=0.0012$ ) from 11.5% to 8.8% in the iV group. The mean TT-TG distance  
58 was significantly decreased ( $p<0.0001$ ) from 12.8 mm to 9.7 mm in the iV group, while  
59 it was significantly increased in the OW group ( $p<0.0001$ ). Concerning the clinical  
60 outcome, the Japanese Orthopaedic Association (JOA) score and the Lysholm knee scores  
61 were significantly increased ( $p<0.0001$ ) at the final follow-up (JOA score: 91.2 points  
62 and 90.1 points, in the OW and iV groups, respectively; Lysholm score: 92.5 points and  
63 89.0 points, in the OW and iV groups, respectively) compared with the preoperative value  
64 (JOA score: 68.3 points and 66.8 points, in the OW and iV groups, respectively; Lysholm  
65 score: 67.9 points and 61.0 points, in the OW and iV groups, respectively) in both groups.

66 **Conclusion:** The patellar height, the posterior tibial slope, and the tibial length did not  
67 change after the iV-HTO, while they were significantly changed after the OW-HTO.  
68 Although the preoperative degrees of varus knee and PF-OA were more severe in the iV  
69 group than those in the OW group, the iV group led to an altered PF joint congruity.

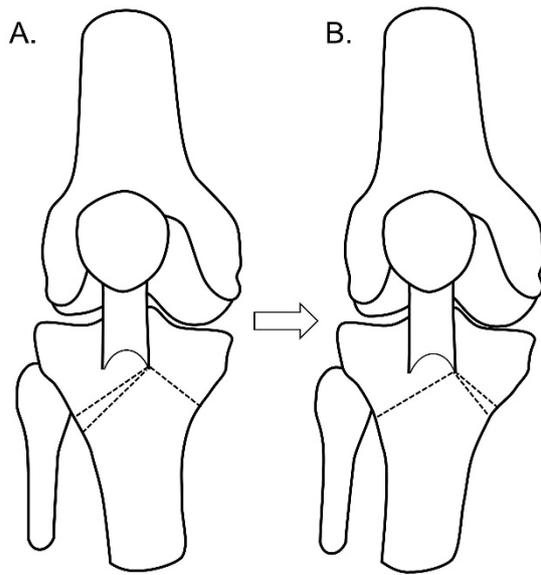
70 **Key words:** high tibial osteotomy; open wedge; patellofemoral joint, Osteoarthritis

71 **INTRODUCTION**

72 Recently, medial opening-wedge (OW) high tibial osteotomy (HTO) has been widely  
73 performed since the improved procedure was introduced,<sup>8,13,25,50-53,61,74</sup> which included  
74 biplanar osteotomy and fixation with a locking plate system.<sup>40,68</sup> Recently, however, it has  
75 been reported that the OW-HTO has several disadvantages.<sup>10,23,43,46,72,74</sup> First, it is  
76 technically difficult to obtain a valgus correction of 15° or greater without any surgical  
77 problems.<sup>46,72,74</sup> Second, the patellar height decreases after surgery.<sup>10,23,31,32,43,73,74</sup> Third,  
78 the length of the lower limb increases after surgery.<sup>35,42,74</sup> Fourth, the posterior tibial slope  
79 (PTS) angle of the tibial plateau increases after surgery.<sup>7,12,16,17,18,28,32,49,63</sup> On the other  
80 hand, lateral closing-wedge (CW) HTO does not have any of these disadvantages.  
81 However, the CW-HTO has different types of disadvantages. First, the length of the lower  
82 limb decreases after surgery.<sup>35,42,</sup> Secondly, the bone mass is reduced in the lateral tibial  
83 plateau, resulting in difficulty of potential total knee arthroplasty (TKA).<sup>5,36,76</sup> Thirdly,  
84 several investigators have reported that the complication rate of the CW-HTO is high,  
85 such as a delayed union, correction loss, and compartment syndrome.<sup>5,66,70</sup> Therefore, an  
86 alternative HTO procedure without these disadvantages should be developed for knee  
87 osteoarthritis (OA) with moderate or severe varus deformity.

88           Inverted V-shaped HTO (iV-HTO), which is classified as a neutral (hemi-closing

89 and hemi-opening) wedge osteotomy, is a potential HTO procedure to solve these  
90 disadvantages (Figure 1).<sup>5,36,76</sup> Namely, in this procedure, the centre of tibial alignment  
91 correction (hinge point) of the HTO is located approximately at the centre of rotation of  
92 angulation (CORA) of the lower limb deformity.<sup>36</sup> According to the principle of the bone  
93 deformity correction,<sup>55</sup> it is expected that this procedure does not affect the patellar height,  
94 the tibial length, or the bone mass of the tibial plateau. The first clinical outcome of the  
95 iV-HTO, in which an external fixator was used to fix the osteotomized tibia, was reported  
96 by Aoki et al<sup>5</sup> in 2006. They reported that the 10-year follow-up results were significantly  
97 better than CW-HTO. However, this procedure had a few disadvantages. First, it was  
98 technically difficult for surgeons to precisely perform the iV osteotomy. Secondly, 10 to  
99 12 weeks were needed to allow for weight-bearing after surgery. To solve these  
100 disadvantages, the authors recently modified the original procedure by developing cutting  
101 guide devices to precisely perform the biplanar osteotomy and a locking plate system for  
102 lateral tibial fixation.<sup>36</sup> However, the influence of the iV-HTO procedure to the patellar  
103 height, the PTS, or the tibial length has not been clinically evaluated as of yet. Moreover,  
104 clinical results of the modified iV-HTO procedure have not been reported.  
105



106  
 107 Figure 1. Diagrams of an inverted V-shaped osteotomy showing (A) a wedge of bone  
 108 resected from the tibia beneath the lateral plateau in the shape of an inverted 'V' and (B)  
 109 valgus correction and grafting of the resected wedged bone block into the triangular gap  
 110 created beneath the medial plateau.

111 Thus, the authors have conducted a comparative study to compare the influence  
 112 of HTO to the patellofemoral (PF) joint and the tibial dimension between the modified  
 113 iV-HTO and the OW-HTO procedures, based on comparison of the radiological and  
 114 clinical results of these procedures. The following hypotheses have been made in this  
 115 study: (1) The patellar height, the PTS, and the tibial length will not change between pre-  
 116 and post-operative evaluations after the iV-HTO, while they may significantly change  
 117 after OW-HTO. (2) The tilting angle and the lateral shift ratio of the patella, and the  
 118 distance between the tibial tubercle and the trochlear groove (TT-TG) may be  
 119 significantly decreased after the iV-HTO in comparison with the preoperative values,  
 120 while they may not change after OW-HTO. The purpose of this study is to test these

121 hypotheses.

## 122 **METHODS**

### 123 **Study Design**

124 This retrospective comparative study involved 234 knees of 203 patients who underwent  
125 HTO from April 2010 to March 2017 in our hospital. The following study protocol was  
126 approved by an institutional review board, and each participant provided their informed  
127 consent. The indication for HTO was a medial OA knee or a varus knee with spontaneous  
128 osteonecrosis of the knee (SONK) in the medial compartment, and pain which was not  
129 reduced by conservative treatment for 3 months or more. Exclusion criteria for HTO were  
130 (1) patients who had an extension loss of  $>15^\circ$ ; (2) patients who had a range of knee  
131 motion  $<130^\circ$ ; (3) patients who had a history of infection in the knee before surgery; (4)  
132 patients who had anteroposterior insufficiency or varus/valgus instability of  $>10^\circ$ . There  
133 were no age restrictions.<sup>22</sup>

134 In the present study, HTO was performed using the iV-HTO procedure (iV  
135 group) or OW-HTO procedure (OW group), according to the following indications. The  
136 indication of the iV-HTO included (1) a knee in which a valgus correction of  $15^\circ$  or more  
137 was needed to change the mechanical axis of the lower limb to 65%, or (2) a knee having  
138 PF-OA of stage 3 or more.<sup>54</sup> On the other hand, the indication of the OW-HTO involved

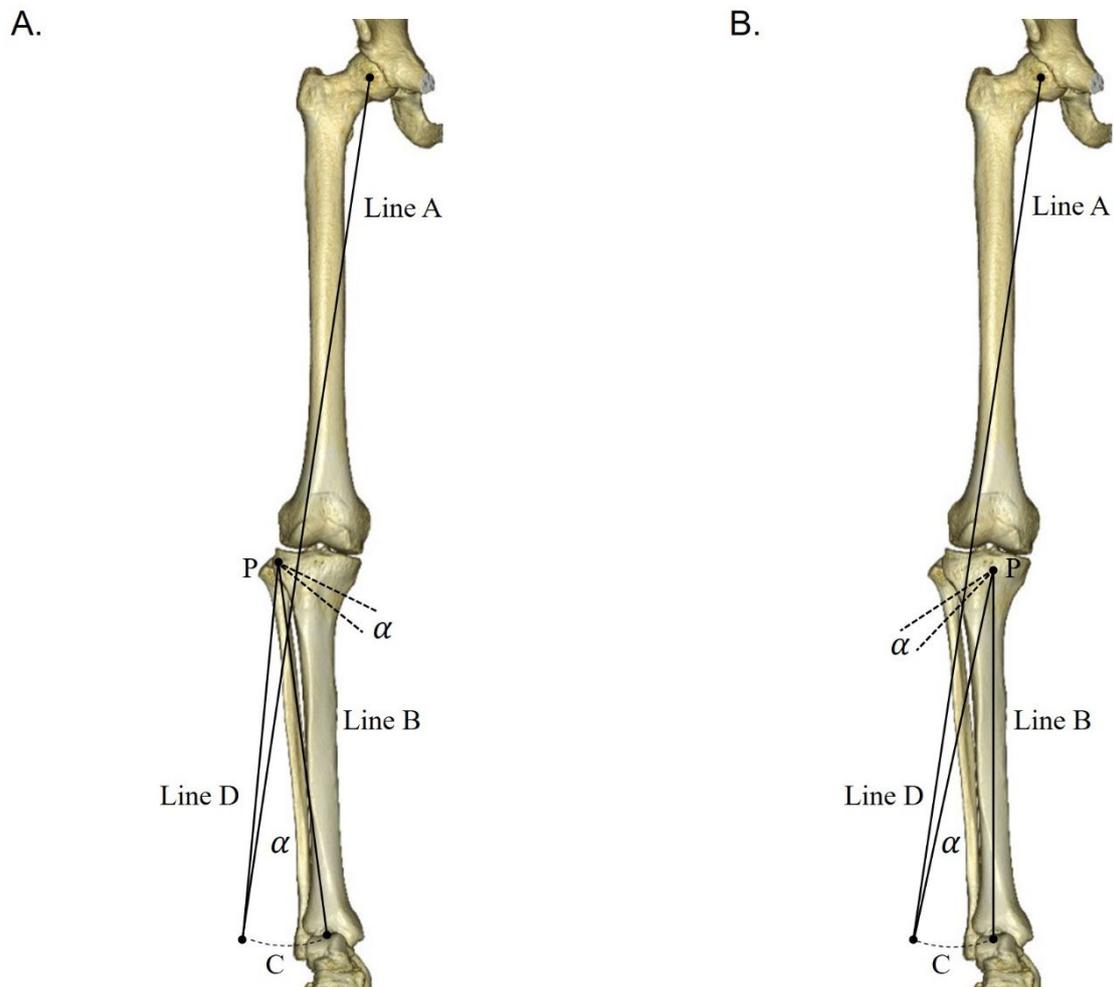
139 (1) a knee in which a valgus correction of  $14^\circ$  or less was enough to change the  
140 mechanical axis to 65%, and (2) a knee having PF-OA of stage 0, 1 or 2. Two senior  
141 orthopaedic surgeons (E.K. and K.Y.), who were sufficiently trained concerning the  
142 procedures, performed all operations. Each knee was radiologically evaluated 3 times,  
143 preoperatively, immediately after surgery, and at 3 years after surgery. Each knee was  
144 clinically evaluated twice, preoperatively and at 3 years after surgery.

#### 145 **Preoperative Planning**

146 Preoperative planning with an appropriate correction angle of the tibia was performed by  
147 a standing full length lower limb anteroposterior radiograph. The surgical planning  
148 methods have been previously described.<sup>36,74</sup> In the OW group, the hinge point 'P' is  
149 located at approximately 5 mm medial from the proximal tibiofibular joint (Figure 2A).  
150 In the iV group, the hinge point 'P' is located at approximately at the medial edge of the  
151 tibial tubercle (Figure 2B). First, a 'line A' is drawn from the centre of the femoral head  
152 through the point 65% lateral from the medial edge of the tibial plateau on the lateral  
153 tibial plateau, because sufficient valgus correction is needed to obtain excellent 10-year  
154 results.<sup>48,60,67,77</sup> Second, a 'line B' is drawn from hinge point P to the centre of the talar  
155 dome. Then an arc C, the centre and the radius of which are the hinge point P and line B,  
156 respectively, is drawn so that the arc is across line A. Next, a 'line D' is drawn from hinge

157 point P to the crossing point between line A and arc C. The angle formed between line B  
158 and line D provides the correction angle. However, double-level osteotomy should be  
159 considered for varus knees with the preoperatively anticipated medial proximal tibial  
160 angle (MPTA) of more than  $95^\circ$ .<sup>47</sup>

161



162

163 **Figure 2.** Preoperative planning

164 In the OW group, the hinge point 'P' is located at approximately 5 mm medial from the  
165 proximal tibiofibular joint (A). In the iV group, the hinge point 'P' is located at  
166 approximately at the medial edge of the tibial tubercle (B). First, a 'line A' is drawn

167 from the centre of the femoral head through the point 65% lateral from the medial edge  
168 of the tibial plateau on the lateral tibial plateau. Second, a 'line B' is drawn from hinge  
169 point P to the centre of the talar dome. Then an arc C, the centre and the radius of which  
170 are the hinge point P and line B, respectively, is drawn so that the arc is across line A.  
171 Next, a 'line D' is drawn from hinge point P to the crossing point between line A and arc  
172 C. The angle (alpha) formed between line B and line D provides the correction angle.

173

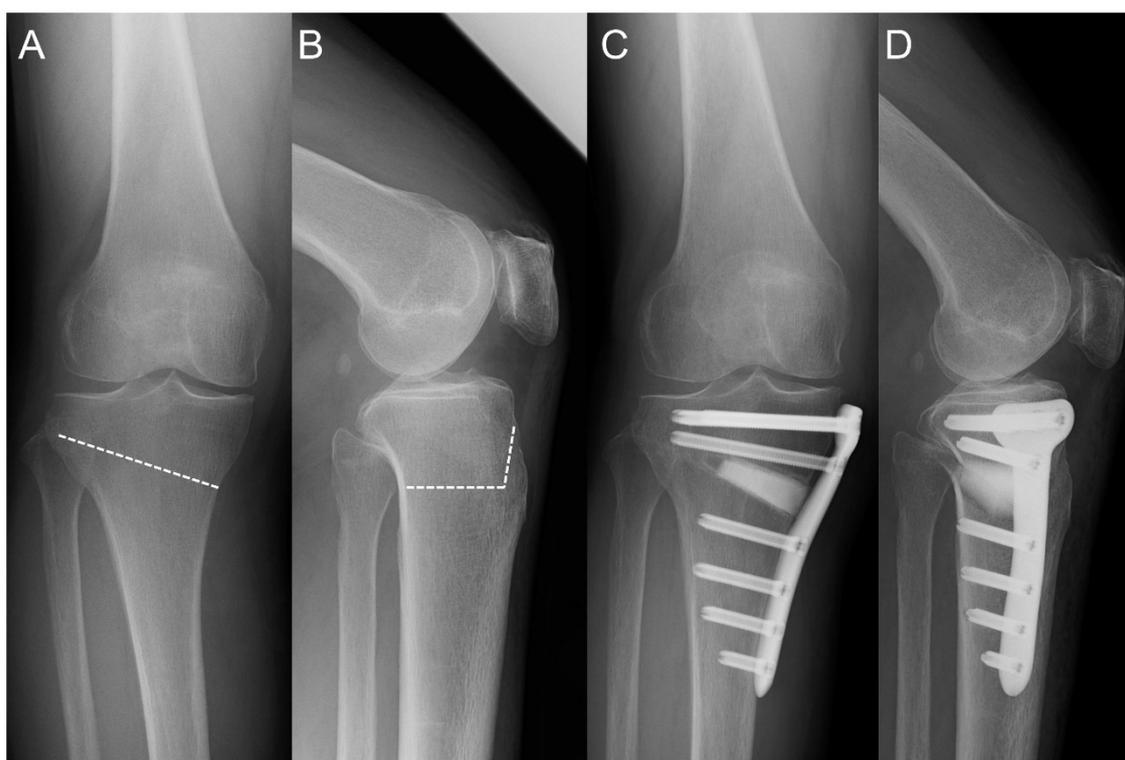
#### 174 **Arthroscopy and additional treatment**

175 Diagnostic arthroscopy was performed with standard anterolateral and anteromedial  
176 parapatellar portals to confirm that there was an isolated medial compartment OA or  
177 SONK. Concomitant procedures can be performed to address medial compartment  
178 chondral injury or meniscal disease.

#### 179 **Surgical Procedure of OW-HTO**

180 This surgery was performed with the original procedure.<sup>52</sup> The proximal tibia was  
181 exposed through a 7-cm medial longitudinal incision. Then, after the complete release of  
182 the distal attachment of the superficial medial collateral ligament (sMCL),<sup>62</sup> guidewires  
183 were inserted into the tibia so that each guidewire precisely reached the proximal  
184 tibiofibular joint. In several biomechanical studies, release of the sMCL is essential for  
185 osteotomy procedure when performing OW-HTO.<sup>2,6,40,56</sup> This procedure is necessary to  
186 avoid not only an increase in medial joint pressure and the PTS, but also neurovascular  
187 injury by inserting a protector to the posterior tibia during surgery. Next, an ascending

188 biplanar osteotomy of the tibial tubercle was performed. The oblique osteotomy site was  
189 then gradually opened using a specially designed spreader (Olympus Terumo  
190 Biomaterials, Tokyo, Japan) based on preoperative planning. Then, two wedge-shaped  
191 beta-tricalcium phosphate spacers (Osferion 60, Olympus Terumo Biomaterials) were  
192 implanted into the opening space. Finally, the tibia was fixed with a locking plate system  
193 (Tomofix, DePuy Synthes, West Chester, PA or TriS Medial HTO plate system, Olympus  
194 Terumo Biomaterials) (Figure 3).



195  
196 Figure 3. Pre- and post-operative radiographs in OW-HTO.  
197 (A) Anteroposterior radiograph before OW-HTO. (B) Lateral radiograph before OW-  
198 HTO. (C) Anteroposterior radiograph after OW-HTO. (D) Lateral radiograph after  
199 OW-HTO. Dotted line: Osteotomy line

#### 200 Surgical Procedure of iV-HTO

201 The details of the iV osteotomy procedure have been previously described.<sup>36,76</sup> A  
202 longitudinal incision was made at the posterolateral aspect of the mid lower leg. A long  
203 oblique osteotomy was made at the central portion of the fibula.<sup>76</sup> A 10-cm anterolateral  
204 curved skin incision was made at the proximal tibia. The anteromedial and posterolateral  
205 periosteums were peeled from the tibia along the medial and lateral osteotomy lines. The  
206 surgeon determined the apex point of the iV osteotomy, which was located approximately  
207 at the point where the medial edge of the patella tendon was attached to the tibial tubercle.  
208 A guidewire was then inserted at this point. The Wedge Cutting Guide (Olympus Terumo  
209 Biomaterials) was attached to the apex wire. The 2 pairs of guidewires were inserted into  
210 the tibia toward the apex wire. First, a coronal ascending osteotomy was made. Second,  
211 a lateral hemi-wedge bone resection was performed along the guidewires. Third, a  
212 Parallel Drill Guide (Olympus Terumo Biomaterials) was attached to the apex wire and  
213 the medial aspect of the tibia. Parallel holes were drilled into the tibia along the medial  
214 osteotomy line. Then, the medial side of the tibia undergoes an osteotomy along the  
215 previously drilled holes. The surgeon performed a valgus correction of the tibia by  
216 manually applying a valgus force to the knee. The locking plate (TomoFix Lateral High  
217 Tibia Plate; DePuy Synthes, or Tris lateral tibia plate, Olympus Terumo Biomaterials)  
218 was fixed on the lateral side of the tibia. Finally, the resected bone block was implanted

219 in the medial opening space (Figure 4).



220

221 Figure 4. Pre- and post-operative radiographs in iV-HTO.

222 (A) Anteroposterior radiograph before iV-HTO. (B) Lateral radiograph before iV-HTO.

223 (C) Anteroposterior radiograph after iV-HTO. (D) Lateral radiograph after iV-HTO.

224 Dotted line: Osteotomy line

### 225 **Postoperative rehabilitation**

226 After surgery, all the patients underwent postoperative management using the same

227 rehabilitation protocol reported previously.<sup>36,52</sup> Straight leg raising and quadriceps setting

228 exercises as well as active and passive knee motion exercises were encouraged from the

229 day after surgery. Partial weight-bearing on the tibia was permitted with crutches at 2

230 weeks after surgery. Full weight-bearing was allowed at 4 weeks after surgery.

### 231 **Radiological evaluation**

232 The following radiological outcomes were evaluated preoperatively, immediately after

233 surgery, and at 3 years after surgery. The degree of OA at the FT and PF joints was  
234 evaluated using the Kellgren–Lawrence classification.<sup>34</sup> The hip–knee–ankle angle  
235 (HKA), defined as the angle between the femoral mechanical axis and the tibial  
236 mechanical axis, the FTA, defined as the angle between the anatomical axis of the femoral  
237 shaft and the axis of the tibial shaft on the fibular side, and the MPTA, defined as the  
238 angle between the proximal tibial joint line and the mechanical axis of the tibial shaft,  
239 were measured on an anteroposterior radiograph of the whole lower limb taken with a  
240 long cassette in the one-leg standing position with the knee joint in extension (Figure 5).  
241 To calculate the mechanical axis, a line was drawn from the centre of the femoral head to  
242 the middle point of the proximal talar joint surface. The mechanical axis percentage was  
243 defined as the horizontal distance from the mechanical axis to the medial edge of the tibial  
244 plateau, divided by the width of the tibial plateau. The entire leg length was defined as  
245 the distance between the top of the femoral head and the centre of the tibial plafond. The  
246 tibial length was defined as the distance between the centre of the proximal tibia and the  
247 centre of the medial tibial plafond. The Insall-Salvati (IS) ratio,<sup>29</sup> the Caton-Deschamps  
248 (CD) ratio<sup>11</sup> and the PTS<sup>4</sup> were estimated on lateral radiographs. The PTS was measured  
249 as the angle between the line perpendicular to the mid-diaphysis of the tibia and the  
250 posterior inclination of the medial tibial plateau on the lateral view. The patellar tilting

251 angle and lateral shift ratio<sup>9,75</sup> were estimated in the skyline view with the knee flexed to  
 252 30°. The tilting angle was defined as the angle between the line intersecting the widest  
 253 bony structure of the patella and the line tangentially passing the anterior surface of the  
 254 femoral condyles. The lateral shift was defined as the ratio of the distance between the  
 255 summit of the lateral femoral condyle and the point at which a line from the lateral edge  
 256 of the patella that is perpendicular to the line that passes through the summits of the  
 257 femoral condyles crosses that line to the distance between the summits of the medial and  
 258 lateral femoral condyles of the femur.

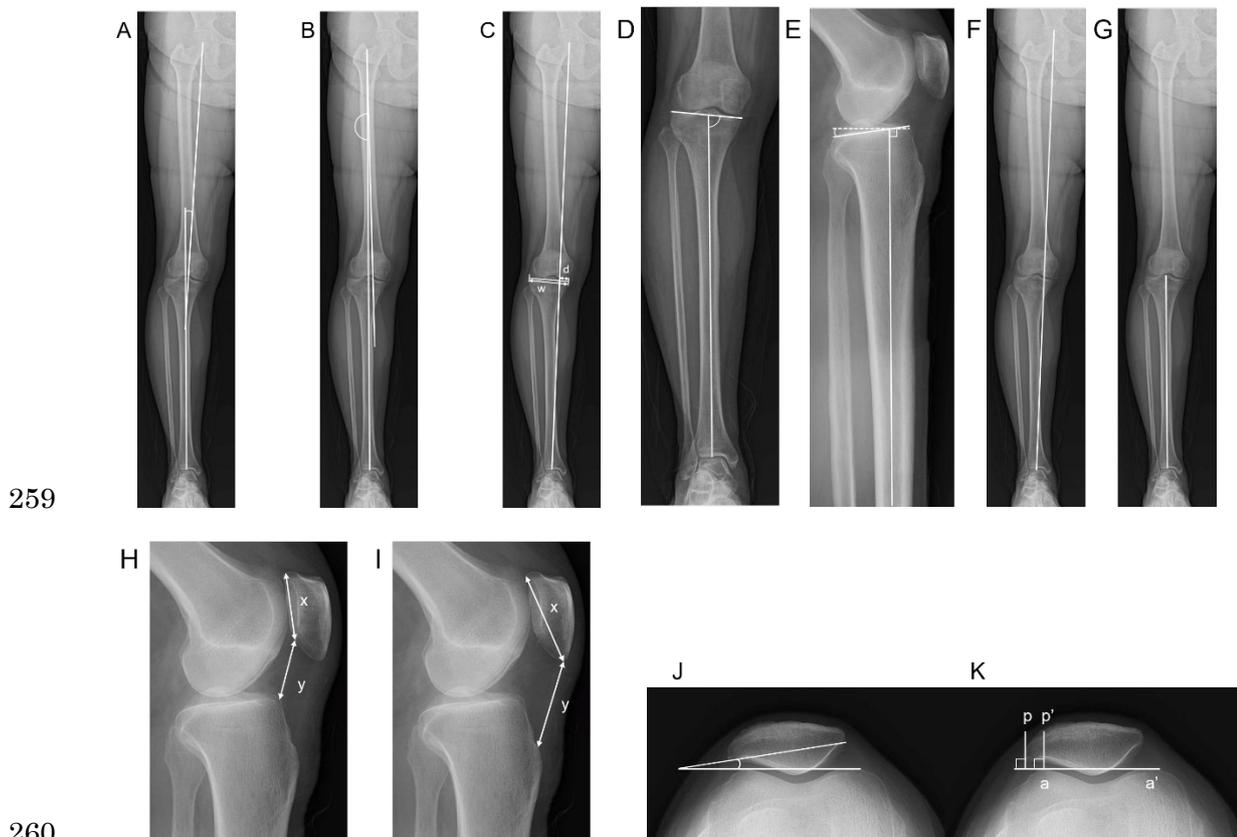


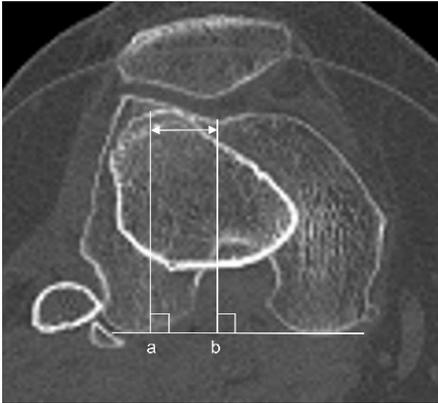
Figure 5. Radiographic assessments.

(A) Hip–knee–ankle angle (HKA). The HKA was defined as the angle between the

263 femoral mechanical axis and the tibial mechanical axis. (B) Femorotibial angle (FTA).  
264 The FTA was defined as the angle between the anatomical axis of the femoral shaft and  
265 the axis of the tibial shaft on the fibular side. (C) Mechanical axis of the lower limb. A  
266 mechanical axis line was drawn from the centre of the femoral head to the middle point  
267 of the proximal talar joint surface. The mechanical axis percentage was defined as the  
268 horizontal distance from the mechanical axis line to the medial edge of the tibial plateau  
269 (d), divided by the width of the tibial plateau (w). (D) Medial proximal tibial angle  
270 (MPTA). The MPTA was defined as the angle between the proximal tibial joint line and  
271 the mechanical axis of the tibial shaft. (E) Posterior tibial slope (PTS). The PTS was  
272 defined as the angle between the line perpendicular to the mid-diaphysis of the tibia and  
273 the posterior inclination of the medial tibial plateau. (F) Entire leg length. The entire leg  
274 length was defined as the distance between the top of the femoral head and the centre of  
275 the tibial plafond. (G) The tibial length was defined as the distance between the centre of  
276 the proximal tibia and the centre of the tibial plafond. (H) Caton-Deschamps (CD) ratio.  
277 The CD ratio was defined as a ratio of the distance (x) between the inferior pole of the  
278 patella and the antero-proximal edge of the tibial plateau divided by the patellar length  
279 (y). (I) Insall-Salvati (IS) ratio. The IS ratio was defined as a ratio of the length of the  
280 patella tendon (the distance between the inferior pole of the patella and the tibial tubercle  
281 (x)) divided by the patellar length (y). (J) Tilting angle. The tilting angle was defined as  
282 the angle between the line intersecting the widest bony structure of the patella and the  
283 line tangentially passing the anterior surface of the femoral condyles. (K) Lateral shift  
284 ratio. The lateral shift ratio was defined as the ratio of the distances  $pp'/aa'$ .  $aa'$  is defined  
285 as the distance between the summits of the medial and lateral femoral condyles.  $pp'$  is  
286 defined as the distance between the summit of the lateral femoral condyle and the point  
287 where a line from the lateral edge of the patella perpendicular to the line that passes  
288 through the summits of the femoral condyles crosses that line.

289 The TT-TG distance<sup>24</sup> was measured from 2 superimposed CT slices, one through the  
290 floor of the groove where the intercondylar notch has a Norman arch shape, and the other  
291 through the middle of the tibial tubercle (Figure 6).

292



293

294 Figure 6. The distance between the tibial tubercle and the trochlear groove (TT-TG).

295 The TT-TG distance was measured from 2 superimposed CT slices, the distance was  
296 defined between the centre of the tibial tubercle (a) on one image and the trochlear groove  
297 perpendicular to the posterior femoral condyles (b) on a second image.

### 298 **Clinical evaluation**

299 The patients were evaluated by use of the Japanese Orthopaedic Association (JOA)  
300 score<sup>5,77</sup> and Lysholm knee score<sup>41</sup> at preoperative and final follow-up periods in our  
301 outpatient clinic. The JOA score is the standard knee function scale in Japan. Based on a  
302 previous study,<sup>5,77</sup> the results were graded as good for total JOA scores of 85 to 100 points,  
303 fair for 70 to 84, and poor for 69 or less.

304 When a complication was clinically or radiologically detected during surgery or follow-  
305 up, it was recorded in the electronic medical record system.<sup>66,74</sup> Intraoperative lateral  
306 hinge fractures were evaluated according to Takeuchi et al.<sup>72</sup>

### 307 **Statistical analysis**

308 An a priori power analysis was performed. Based on our previous studies,<sup>5,31,52,62</sup> a sample  
309 size of 191 patients (220 knees) was calculated to have greater than 85% power to test the

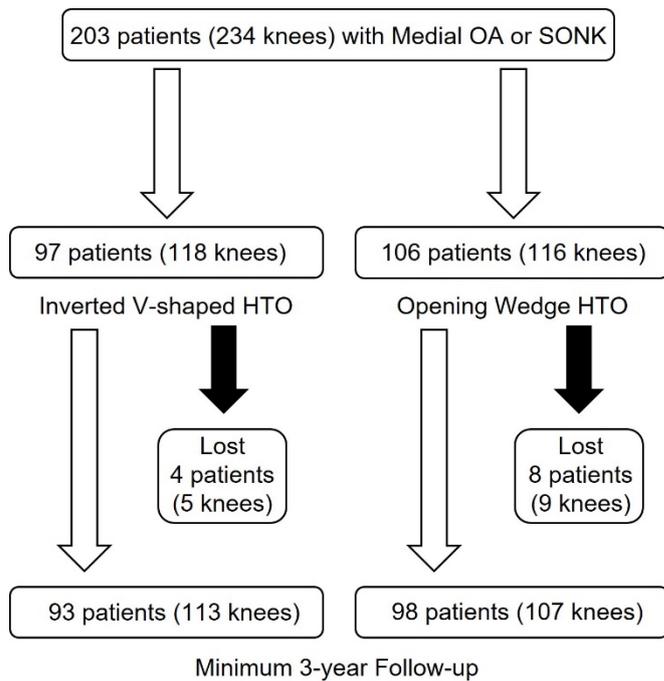
310 hypothesis. All data are shown as means with a standard deviation. The paired Student t-  
311 test was used to assess the clinical and radiological differences between before and after  
312 surgery. The Mann–Whitney U test and the chi square test were used to assess the  
313 demographic parameter, the clinical and radiological differences between the OW and iV  
314 groups. JMP Pro10.0 for Windows (SAS Institute Japan) was used for statistical analyses.  
315 The significance level was set at  $p = 0.05$ .

316

## 317 **RESULTS**

### 318 **Follow-up examinations**

319 Consequently, in the 234 knees, 118 knees underwent iV-HTO and 116 knees underwent  
320 OW-HTO (Figure 7). The authors tried to follow up these knees for 3 years or more after  
321 surgery in the outpatient clinic. However, 12 patients (14 knees) were lost to follow-up.  
322 Therefore, a total of 220 knees of 191 patients were subjects in this study. Among the  
323 subjects, 113 knees of 93 patients underwent iV-HTO (iV group), while 107 knees of 98  
324 patients underwent OW-HTO (OW group). Patients underwent follow-up at an average  
325 of 65.7 months (range, 40.1-132.1 months) and 67.2 months (range, 39.9-135.5 months)  
326 in the OW and iV groups, respectively.



327

328 Figure 7. Follow-up examinations.

329 HTO, high tibial osteotomy; OA, osteoarthritis; SONK, spontaneous osteonecrosis of the  
 330 knee.

331

332 **Patient Demographics**

333 There were 65 men and 126 women with a mean age of 61.0 years (range; 41 to 81) at  
 334 the time of surgery. Their background characteristics are shown in Table 1.

335 TABLE 1. Background characteristics and Radiographic OA grade of the patients<sup>a</sup>

	OW group (n=98, 107 knees)	iV group (n=93, 113 knees)	p value
Age (years)	62.5 (6.6) (range: 42-78)	59.9 (9.1) (range: 41-81)	0.0366
Male/Female (patients) <sup>a</sup>	28/70	37/56	0.1021
Rt/ Lt <sup>a</sup>	47/60	61/52	0.1105
Unilateral/ Bilateral <sup>a</sup>	89/9	73/20	0.0177
Height (cm)	157.3 (7.9)	160.1 (9.0)	0.0244
Weight (kg)	64.7 (10.9)	67.5 (12.9)	0.0891
Body mass index (kg/m <sup>2</sup> )	26.1 (3.9)	26.2 (3.9)	0.9840
Femorotibial grade <sup>a,b</sup> (No. of Knees)			< 0.0001 <sup>c,d</sup>
Preoperative/Final Follow-up			
Grade 0	0/0	0/0	
Grade 1	2/1	2/1	
Grade 2	30/29	15/11	
Grade 3	71/72	61/63	
Grade 4	4/5	35/38	
Patellofemoral grade <sup>a,b</sup> (No. of Knees)			< 0.0001 <sup>c,d</sup>
Preoperative/Final Follow-up	*		
Grade 0	22/17	10/7	
Grade 1	75/67	29/27	
Grade 2	10/18	39/41	
Grade 3	0/5	26/29	
Grade 4	0/0	9/9	
Length of follow-up periods (Mo)	65.7 (21.8) (range:40.1- 132.1)	67.2 (17.6) (range: 39.9-135.5)	0.1902

336 <sup>a</sup>Data except for patient sex, rt/lt, uni/bilateral, and femorotibial and patellofemoral grades  
 337 are reported as mean (standard deviation).

338 <sup>b</sup>Determined via the Kellgren-Lawrence grading system.

339 <sup>c</sup>Preoperative OW group vs iV group.

340 <sup>d</sup>Postoperative OW group vs iV group.

341 \*Significant difference between pre- and post-operative values.

342 **Additional Treatment**

343 Degenerative findings were observed in the medial menisci of all cases. Partial  
344 meniscectomy was performed for unstable meniscal tears in 127 knees. Debridement was  
345 performed for fragmentation of the cartilage. No treatment was administered for softening  
346 or fissuring of the articular cartilage. Osteochondral autograft transfer was carried out in  
347 14 knees using the OATS system (Arthrex, Naples, FL, USA). A donor graft was  
348 harvested from the lateral femoral trochlea.

349 TABLE 2. Arthroscopy and Additional treatment

	OW group (n=98, 107 knees)	iV group (n=93, 113 knees)	p value
Partial meniscectomy	68 knees	59 knees	0.0888
Medial meniscus			
Suture	4 knees	6 knees	0.5760
Medial meniscus			
Osteochondral autograft transfer	9 knees	5 knees	0.2260
Medial femoral condyle			

350

351 **Radiological evaluation**

352 The demographic parameters and the results of the radiographic measurements are listed  
353 in Tables 1, 3 and 4. Concerning the preoperative OA grades at FT and PF joints, the iV  
354 group was significantly higher than the OW group ( $p < 0.0001$ ) (Table 1). In the iV group,

355 no significant differences were seen between the pre- and postoperative radiographic FT-  
356 and PF-OA grades (Table 1). In the OW group, significant PF-OA progression was found  
357 at the final follow up ( $p=0.0388$ ). Regarding preoperative coronal lower leg alignment,  
358 the iV group had severe varus deformity (Table 3). The preoperative values for the HKA,  
359 FTA, mechanical axis, and MPTA were significantly higher in the iV group than in the  
360 OW group ( $p<0.0001$ ). Postoperatively, the HKA, FTA, mechanical axis, and MPTA  
361 changed significantly ( $p <0.0001$ ) compared with the preoperative values in both groups.  
362 There were no significant differences in the postoperative HKA, FTA, mechanical axis,  
363 and MPTA between the two groups. There was no significant difference in each parameter  
364 between the immediately after surgery and final follow-up periods in both groups.

365           Postoperatively, the PTS was significantly increased in the OW group  
366 ( $p<0.0001$ ), while there were no significant differences in the iV group (Table 3). The  
367 postoperative PTS was significantly higher ( $p<0.0031$ ) in the OW group than in the iV  
368 group.

369           Concerning the leg length, the postoperative entire leg length and tibial length  
370 were significantly increased after surgery compared with the preoperative values in the  
371 OW group ( $p<0.0001$ ) (Table 3). Although the entire leg length was significantly  
372 increased ( $p=0.0003$ ), there were no significant differences in the tibial length between

373 the pre- and post-operative periods in the iV group.

374 TABLE 3. Pre- and Post-operative radiographic measurement of OW- and iV-HTOs

	Pre-operative	Immediately	Post-operative	p value
HKA (°)				
OW group	-5.4 (3.1)	4.3 (2.4)	4.4 (2.4)	<0.0001 <sup>a</sup> 0.1301 <sup>b</sup>
iV group	-8.7 (4.1)*	3.5 (3.8)	3.6 (3.9)	<0.0001 <sup>a</sup> 0.0793 <sup>b</sup>
FTA (°)				
OW group	179.8 (2.6)	170.1 (2.1)	170.3 (2.4)	<0.0001 <sup>a</sup> 0.0827 <sup>b</sup>
iV group	183.2 (4.1)*	168.8 (3.1)	169.9 (3.5)	<0.0001 <sup>a</sup> 0.2669 <sup>b</sup>
Mechanical axis (%)				
OW group	25.9 (12.2)	65.8 (10.3)	66.0 (10.6)	<0.0001 <sup>a</sup> 0.0966 <sup>b</sup>
iV group	10.2 (18.9)*	64.6 (14.9)	65.9 (11.9)	<0.0001 <sup>a</sup> 0.9548 <sup>b</sup>
MPTA (°)				
OW group	84.8 (2.5)	93.4 (2.1)	93.5 (2.0)	<0.0001 <sup>a</sup> 0.1377 <sup>b</sup>
iV group	82.3 (2.9)*	93.9 (1.9)	94.0 (2.3)	<0.0001 <sup>a</sup> 0.5216 <sup>b</sup>
PTS (°)				
OW group	8.5 (2.9)	10.5 (3.8)	10.5 (3.6)	<0.0001 <sup>a</sup> 0.3477 <sup>b</sup>
iV group	8.4 (3.0)	8.8 (4.0)*	8.9 (4.0)*	0.0736 <sup>a</sup> 0.0777 <sup>b</sup>
Whole leg length (mm)				
OW group	730.5 (40.1)	739.4 (39.8)	739.9 (39.6)	<0.0001 <sup>a</sup> 0.7552 <sup>b</sup>
iV group	768.9 (58.9)*	771.4 (58.6)*	771.3 (59.0)*	0.0003 <sup>a</sup> 0.6309 <sup>b</sup>
Tibial length (mm)				

OW group	322.7 (20.0)	331.5 (19.9)	331.7 (20.1)	<0.0001 <sup>a</sup> 0.4782 <sup>b</sup>
iV group	341.1 (29.8)*	340.6 (30.0)	341.5 (29.4)	0.3692 <sup>a</sup> 0.1288 <sup>b</sup>

375 Data are reported as mean (standard deviation). HKA, the hip-knee- ankle angle; FTA,  
376 the lateral femorotibial angle; MPTA, the medial proximal tibial angle; PTS, the posterior  
377 tibial slope.

378 <sup>a</sup>Preoperative vs final follow-up data.

379 <sup>b</sup>Immediately after surgery vs final follow-up data.

380 \*Significant difference between the OW and the iV groups.

381 For the CD ratio, the OW group showed a significant decrease after surgery  
382 compared with the preoperative value ( $p < 0.0001$ ), while there was no significant  
383 difference in the iV group (Table 4). The postoperative CD ratio was significantly smaller  
384 ( $p < 0.0001$ ) in the OW group than in the iV group. Regarding the IS ratio, there were no  
385 significant differences in the pre- and postoperative values between the two groups.

386 Regarding changes in the axial view of the PF joint, the tilting angle was  
387 significantly decreased after surgery compared with the preoperative values in both  
388 groups ( $p < 0.0001$ ) (Table 4). For the lateral shift ratio, the iV group showed significant  
389 medial translation after surgery compared with the preoperative value ( $p = 0.0012$ ), while  
390 there was no significant change in the OW group. There were significant differences  
391 ( $p < 0.0001$ ) in the postoperative lateral shift ratio between the two groups. Postoperatively,  
392 the TT-TG distance was significantly decreased in the iV group ( $p < 0.0001$ ), while this  
393 value was significantly increased in the OW group ( $p < 0.0001$ ). The postoperative TT-TG

394 distance was significantly smaller ( $p < 0.0059$ ) in the iV group than in the OW group.  
 395 There were no significant differences in the tilting angle, the lateral shift ratio, and the  
 396 TT-TG distance between the immediately after surgery and the final follow-up data in  
 397 both groups.

398 TABLE 4. Change in patellofemoral joint congruity with OW- and iV-HTOs

	Pre-operative	Immediately	Post-operative	p value
Carton-Deschamps ratio				
OW group	0.95 (0.12)	0.80 (0.12)	0.79 (0.12)	<0.0001 <sup>a</sup> 0.3715 <sup>b</sup>
iV group	0.88 (0.13)*	0.89 (0.12)*	0.88 (0.12)*	0.6297 <sup>a</sup> 0.2643 <sup>b</sup>
Insall-Salvati ratio				
OW group	1.02 (0.13)	1.00 (0.13)	1.00 (0.13)	0.0262 <sup>a</sup> 0.1458 <sup>b</sup>
iV group	0.99 (0.12)*	0.96 (0.13)	0.97 (0.13)	0.1083 <sup>a</sup> 0.1065 <sup>b</sup>
Tilting angle (°)				
OW group	7.4 (3.2)	7.2 (3.1)	7.1 (3.1)	<0.0001 <sup>a</sup> 0.4043 <sup>b</sup>
iV group	8.4 (4.6)	6.4 (3.6)	6.5 (3.3)	<0.0001 <sup>a</sup> 0.1992 <sup>b</sup>
Lateral shift ratio (%)				
OW group	12.1 (4.5)	12.1 (4.6)	12.1 (4.7)	0.8164 <sup>a</sup> 0.5039 <sup>b</sup>
iV group	11.5 (6.7)*	9.0 (8.4)*	8.8 (9.1)*	0.0012 <sup>a</sup> 0.6181 <sup>b</sup>
TT-TG distance (mm)				
OW group	10.5 (2.8)	11.5 (3.2)	11.6 (3.3)	<0.0001 <sup>a</sup> 0.3365 <sup>b</sup>
iV group	12.8 (3.9)*	9.5 (4.2)*	9.7 (4.1)*	<0.0001 <sup>a</sup> 0.2871 <sup>b</sup>

399 Data are reported as mean (standard deviation).

400 TT-TG, the tibial tubercle and the trochlear groove.

401 <sup>a</sup>Preoperative vs final follow-up data.

402 <sup>b</sup>Immediately after surgery vs final follow-up data.

403 \*Significant difference between the OW and the iV groups.

#### 404 **Clinical evaluation**

405           Concerning the clinical outcome, the JOA score and the Lysholm knee scores  
406 were significantly increased at the final follow-up compared with the preoperative value  
407 in both groups ( $p < 0.0001$ ) (Table 5). There were no significant differences in the pre- and  
408 post-operative JOA score and Lysholm score between the 2 groups. The functional  
409 gradings of the JOA scores are presented in Table 5. At the final follow-up, the results  
410 were graded as good in 96 knees (89.7%), fair in 8 knees (7.5%) and poor in 3 knees  
411 (2.8%) in the OW group. In the iV group, the results were good in 93 knees (82.3%), fair  
412 in 16 knees (14.2%) and poor in 4 knees (3.5%) (Table 5). There was no significant  
413 difference in the functional grading of the JOA score between the two groups.

414 TABLE 5. Change in clinical outcomes with OW- and iV-HTOs

	Pre-operative	Post-operative	p value
JOA score (points)			
OW group	68.3 (10.6)	91.2 (8.3)	<0.0001
iV group	66.8 (10.0)	90.1 (6.4)	<0.0001
Good			
OW group	10 knees	96 knees	<0.0001
iV group	3 knees	93 knees	<0.0001
Fair			
OW group	42 knees	8 knees	
iV group	48 knees	16 knees	
Poor			
OW group	55 knees	3 knees	
iV group	62 knees	4 knees	
Lysholm score (points)			
OW group	67.9 (13.8)	92.5 (6.7)	<0.0001
iV group	61.0 (16.2)	89.0 (9.5)	<0.0001

415 Data are reported as mean (standard deviation).

416 JOA; Japanese Orthopaedic Association

417

### 418 **Complications**

419 In the OW group, lateral hinge fractures occurred in 28 knees (26%) (Table 6). After  
 420 surgery, 2 knees had superficial infections around the skin incision, although no patients  
 421 had deep infections. Unacceptable over-correction (< FTA 160°) occurred in 1 knee,  
 422 correction loss greater than 5° occurred in 2 knees, and nonunion occurred in 3 knees. In  
 423 the patient with unacceptable overcorrection, we performed revision OW-HTO at 1 week  
 424 after the first surgery. In the 2 patients with correction loss, TKA was performed 12

425 months after surgery. In the 3 patients with nonunion, after 6 months a revision OW-HTO  
426 and iliac bone graft was performed by use of bilateral plate fixation.

427           In the iV group, no patients had superficial and deep infections. Unacceptable  
428 over-correction occurred in 1 knee, correction loss occurred in 1 knee, and nonunion  
429 occurred in 3 knees. In the 3 patients with unacceptable overcorrection or nonunion, we  
430 performed revision iV-HTO and iliac bone graft was performed by use of bilateral plate  
431 fixation. No cases of popliteal vascular injury, peroneal nerve injury, tibial tubercle  
432 fracture, or compartment syndrome were noted in both groups.

433           Each patient underwent an additional procedure approximately 1 year (mean, 13  
434 months; range, 10-32 months) after the initial surgery to remove the implanted plate and  
435 screws. During the plate removal surgery, implant failure was found or occurred in 9  
436 knees and 2 knees in OW and iV groups, respectively (Table 6). We confirmed that 14  
437 locking screws were broken. In these cases, we removed the inserted screw by hollowing  
438 out the bone tissue with a core reamer. There were no significant differences in the  
439 complication rate without implant failure between the two groups.

440 TABLE 6. Complications in Opening Wedge and inverted V-shaped High Tibial  
 441 Osteotomies.

	OW group (n=98, 107 knees)	iV group (n=93, 113 knees)	P value
Lateral hinge fracture	28 (26%)	n/a	n/a
Infection	2 (2%)	0 (0%)	0.1443
Over correction	1 (1%)	1 (1%)	0.9691
Correction loss	2 (2%)	1 (1%)	0.5293
Nonunion	3 (3%)	3 (3%)	0.9460
Implant failure	9 (8%)	2 (2%)	0.0239

442 No. of Knees (%)

443 n/a, not available.

444

445 **DISCUSSION**

446 The main findings of the present study were that, first, even though the tibial correction  
 447 angle was significantly greater in the iV group than in the OW group, the patellar height,  
 448 the PTS, and the tibial length did not change in the iV group. On the other hand, the  
 449 patella height was significantly reduced, and the PTS and the tibial length were  
 450 significantly increased in the OW group. Second, the lateral shift ratio of the patella and  
 451 the TT-TG distance were significantly decreased in the iV group, compared with the  
 452 preoperative values, while the lateral shift ratio did not change in the OW group. Third,  
 453 even though the preoperative OA grade and the degree of knee deformity were more  
 454 severe in the iV group than in the OW group, the 3-year clinical results were significantly  
 455 improved in comparison with the preoperative status in each group, and there were no

456 differences in the 3-year results between the two groups.

457           Concerning the patellar height, this study showed that no changes occur in the  
458 CD ratio and IS ratio after iV osteotomy. We considered that the centre of tibial alignment  
459 correction (hinge point) of iV osteotomy was located approximately at the medial portion  
460 of the distal attachment of the patella tendon. Therefore, this osteotomy does not change  
461 the patellar height after surgery. The most frequent radiographic change seen after the  
462 OW-HTO procedure with ascending tibial tuberosity osteotomy was patella baja as a  
463 deformity of the tibia.<sup>10,32,43,73</sup> Patella baja is known as an adverse deformity of the knee.  
464 Altered patellar height may induce anterior knee pain and result in long-term PF cartilage  
465 degeneration.<sup>64</sup> Namely, Yabuuchi et al<sup>74</sup> reported complications after OW-HTO.  
466 According to the measurement with the CD ratio, the patellar height was reduced under  
467 0.6 or more in 37.6% of the patients. Recently, Goshima et al<sup>23</sup> reported that cartilage  
468 degeneration was frequently found in the PF joint in patients after the OW-HTO surgery.  
469 Although the patella baja induced by the OW-HTO did not result in a significant reduction  
470 of the functional results in the short-term clinical evaluation,<sup>16</sup> there is a risk that the  
471 functional results may be significantly reduced in the long-term follow-up evaluation.  
472 Furthermore, lower patellar height potentially increases the load of the PF joint, resulting  
473 in PF-OA and anterior knee pain.<sup>69</sup> Stoffel et al<sup>69</sup> reported that OW-HTO led to a

474 significant elevation in PF cartilage pressure at 30°, 60°, and 90° of knee flexion in a  
475 cadaveric biomechanical experiment. Some other radiologic and biomechanical studies  
476 have indicated an increase of PF contact pressure and the progression of PF-OA after  
477 OW-HTO.<sup>10,19,39</sup> Kameda et al<sup>31</sup> also reported that a statistically significant decrease of  
478 the patellar height and degradation of the PF cartilage after OW-HTO. Their study  
479 demonstrated that the OW-HTO procedure significantly increased stress distribution  
480 patterns of the femoral lateral trochlea and the medial portion of the patellar lateral facet  
481 using the CT-osteodensitometry method. OW-HTO is often associated with decreased  
482 patellar height due to distal and lateral movement of the tibial tuberosity. Previous  
483 studies<sup>17,19</sup> reported that patellar height significantly increased with CW-HTO. On the  
484 other hand, in the iV-HTO, there were no significant differences in the patellar height  
485 between the pre- and post-operative periods. Recently, several authors reported  
486 descending tibial tuberosity osteotomy (DTO) in OW-HTO.<sup>3,20,69</sup> Biomechanically, DTO  
487 does not increase contact pressure in the PF joint. However, the long-term effect of DTO  
488 on the PF joint is little known.

489           With respect to PF joint congruency, Gaasbeek et al<sup>19</sup> reported that OW- and  
490 CW-HTOs caused the patella to tilt more medially. A systematic review and meta-analysis  
491 revealed that tilting angle was significantly decreased, but the lateral shift ratio did not

492 differ significantly after OW-HTO.<sup>38</sup> Kameda et al<sup>31</sup> suggested that the medial tilt of the  
493 patella occurred because of lateral and distal shifts of the tibial tuberosity forcing up the  
494 lateral side of the femur and patella. In the present study, the tilting angle and the lateral  
495 shift ratio after OW-HTO were similar to those in previous studies.<sup>9,23,38,39</sup> Ishimatsu et  
496 al<sup>30</sup> reported that the tilting angle was significantly decreased, and the lateral shift ratio  
497 showed significant translation in a medial direction after the hybrid CW-HTO. IV-HTO  
498 procedure is classified as a neutral osteotomy. The centre of tibial alignment correction is  
499 located approximately at the CORA of the lower-limb deformity, which is located at  
500 medial side of the tibial tuberosity. On the other hand, the hybrid CW-HTO is classified  
501 as a CW osteotomy. The centre of alignment correction divides the proximal oblique  
502 osteotomy line by about 2 to 1 from lateral to medial. In addition, the present study  
503 showed that the TT-TG distance was significantly decreased in the iV group between the  
504 2 periods, while it was significantly increased in the OW group. In the OW-HTO, the  
505 hinge point is located near the proximal tibiofibular joint. After opening the osteotomy  
506 site, the patellar height was decreased because of a distal and lateral shift of the tibial  
507 tuberosity, resulting in an increase of the TT-TG distance. In the iV-HTO, the hinge point  
508 is located at medial side of the tibial tuberosity. After closing the lateral osteotomy site,  
509 this osteotomy could antero-medialize the tibial tuberosity, resulting in a reduction of the

510 TT-TG distance. However, these values were relatively small since it is also still within  
511 normal reference values. Therefore, clinical relevance remains unclear at mid-term  
512 follow-up.

513           The effects of HTO on the PTS have been widely debated.<sup>7,12,16,17,18,28,32,49,63</sup> It is  
514 generally thought that the PTS increases after OW osteotomy and decreases after CW  
515 osteotomy. Ducat et al<sup>16</sup> reported that 14% of the OW osteotomies increased PTS by 5°,  
516 whereas 12% of the CW osteotomies led to a decrease of 5° or more of the PTS. A meta-  
517 analysis<sup>49</sup> showed that the PTS increased 2.02° after OW-HTO and decreased 2.35° after  
518 CW-HTO. Modification of PTS is a source of instability and excessive anteroposterior  
519 tibial translation that may encourage the progression of OA.<sup>1,27</sup> The previous studies<sup>1,15,21</sup>  
520 have shown the linear relationship between the PTS and tibial translation during a  
521 monopodal stance: the more the tibial slope increases, the more the anterior tibial  
522 translation increases. On the other hand, CW osteotomy produces a decrease in the PTS,  
523 which distributes the stresses on the posterior compartment. This study showed that the  
524 PTS was increased after OW-HTO surgery. An OW osteotomy with anterior and  
525 posteromedial spaces of the same height results in an increase in the PTS.<sup>44</sup> Slope changes  
526 after OW-HTO may also be caused by an incomplete posterior corticotomy, whereas  
527 changes after CW-HTO may result from inadequate bony removal from the posterior part

528 of the wedge; both of these changes may be due to surgeons' concerns about posterior  
529 neurovascular injury during OW- or CW-HTO.<sup>65</sup> This study showed that the PTS did not  
530 change after iV-HTO surgery. We considered that the lateral wedge volume of the iV  
531 osteotomy is smaller than that of the CW osteotomy, because the hinge point is located  
532 near the centre of the tibial condyle.

533         There was no general consensus about the extent to which the change in leg  
534 length could result in clinically relevant problems such as back pain and progression of  
535 knee OA due to alteration of gait kinematics.<sup>71</sup> Some degree (less than 2 cm) of leg length  
536 discrepancy can be allowed in humans because of a compensatory mechanism that  
537 dynamically lengthens the shorter limb and shortens the longer limb,<sup>59</sup> probably to  
538 minimize the displacement of the body center of mass and consequently reduce body  
539 energy expenditure.<sup>33</sup> However, a leg length discrepancy-whether lengthening or  
540 shortening-should be avoided as much as possible, because previous studies demonstrated  
541 that leg lengthening, even by less than 1 cm, increases the chance of developing knee OA  
542 in the longer limb,<sup>26</sup> and that correcting leg length discrepancy of only 5.6 mm relieved  
543 chronic low back pain.<sup>14</sup> Magnussen et al<sup>42</sup> compared leg-length change after OW- and  
544 CW-HTOs. In the OW group, entire leg length increased 5.5 mm, and tibia length  
545 increased 4.3 mm. In the CW group, entire leg length decreased 2.7 mm, and tibia length

546 decreased 4.1 mm. The result of the meta-analysis<sup>35</sup> showed that the OW-HTO resulted  
547 in an 8-mm greater leg length than CW-HTO. This small difference, although less than 1  
548 cm, could induce clinically important symptoms. Yabuuchi et al<sup>74</sup> reported that there was  
549 a significant correlation between the wedge-opened distance and the length of the tibia.  
550 The shift in the weight-bearing axis from the medial opening cortex to the lateral plateau  
551 offsets the effect of tibial lengthening after an OW-HTO. In the present study, although  
552 the entire leg length was significantly increased in both groups (OW; mean 9.4 mm, iV;  
553 2.4 mm), there were no significant differences in the tibial length between the pre- and  
554 post-operative periods in the iV group. Therefore, iV osteotomy resulted in significantly  
555 smaller changes in the leg length than OW osteotomy. Therefore, orthopedic surgeons  
556 should carefully consider leg length changes when deciding the type of HTO. Thus, we  
557 consider that OW-HTO is not recommended for knees that need large alignment  
558 correction with regards to the patellar height, PTS, and leg length changes.

559         Recently, several techniques of combined osteotomy have been reported.<sup>45,57,58</sup>  
560 Papp et al<sup>57</sup> performed a proximal osteotomy parallel to the tibial plateau, followed by a  
561 distal osteotomy extending from the lateral part of the tibia to the line of the proximal  
562 osteotomy at the center of the tibial condyle. A combined osteotomy with lateral closing  
563 then medial opening utilizing the removed lateral bone wedge. They noted that the

564 combined osteotomy resulted in significantly smaller changes in the PTS angle and IS  
565 values than CW osteotomy. They concluded that the combined osteotomy is better at  
566 preserving the normal or near normal condition of the knee than CW osteotomy. Porter et  
567 al<sup>58</sup> reported that CW osteotomies produced patellar ascent by an average of 13%, OW  
568 osteotomies produced descent by an average of 21%, and the combined osteotomy mean  
569 showed any minimal change. The combined osteotomy minimizes changes in patellar  
570 height. A combination of lateral CW and medial OW osteotomy should produce a patellar  
571 height closer to neutral. However, osteotomy line of their combined osteotomy<sup>45,57,58</sup> was  
572 horizontal plane. On the other hand, the iV-shaped osteotomy may increase angular  
573 stability of the post-osteotomy tibia against shear forces after valgus correction. The  
574 combined osteotomy offers some advantages over traditional types: the removed wedge  
575 is thinner, but still can tighten the medial collateral ligament and, in CW, decrease the  
576 slackness produced in the lateral collateral ligament. The combined osteotomy allows the  
577 ability to adjust the patellar height. In addition, performing TKA is easier after combined  
578 osteotomy than after OW osteotomy because the shortening of the patella tendon after  
579 combined osteotomy is smaller than after OW osteotomy. To perform the same correction  
580 during combined osteotomy, a bone wedge must be removed that is approximately 50%  
581 smaller than the removed wedge at CW osteotomy. Less bone loss after combined

582 osteotomy eases the tibial bone resection during the subsequent TKA. Residual proximal  
583 tibial deformity affects the degree of difficulty in possible future TKAs.<sup>37</sup>

584           Concerning the clinical outcome, the JOA score and the Lysholm knee scores  
585 were significantly increased at the final follow-up after 3 years compared with the  
586 preoperative value in both groups. Although the preoperative OA grade and the degree of  
587 varus deformity were more severe in the iV group than in the OW group, there were no  
588 significant differences in the post-operative JOA score and Lysholm score between the 2  
589 groups. Aoki et al<sup>5</sup> compared the results ten years after an iV-HTO using an external  
590 fixator with those of a historical series of conventional CW osteotomies. They concluded  
591 that the iV-HTO was significantly better in the postoperative clinical outcome than CW-  
592 HTO. They suggested that the iV osteotomy may offer more dependable long-term results  
593 than traditional CW osteotomy. Although there were no significant differences in the  
594 radiographic FT-OA grades between the pre- and postoperative periods in both groups,  
595 significant PF-OA progression was found in the OW group at the final follow up period.  
596 Regarding the complication rate, there were no significant differences between the two  
597 groups.

598           There are some limitations in this study. First, the indication of 2 HTO  
599 procedures was different as previously mentioned. A weakness of our study is its reliance

600 on a historical control and a lack of random allocation. Therefore the outcome between  
601 the two groups cannot be attributed to a difference in the two procedures with certainty.  
602 In the future, we recommend using the iV technique for routine use. Second, retrospective  
603 nature of the study introduces a number of confounding factors and risk of selection bias,  
604 etc. Third, the follow-up period averaged only 3 years, and a longer-term follow-up is  
605 needed. Further long-term studies are needed to assess the subjective and objective patient  
606 outcomes of iV osteotomy in patients with severe varus malalignment.

607           In conclusion, this study demonstrated that the patellar height, the posterior tibial  
608 slope, and the tibial length did not change after the iV-HTO, while they were significantly  
609 changed after the OW-HTO. Although the preoperative degrees of varus knee and PF-OA  
610 were more severe in the iV group than those in the OW group, the iV group led to an  
611 altered PF joint congruity. Therefore, in patients with varus knee combined with PF-OA  
612 preoperatively, iV-HTO may be a more effective than OW-HTO.

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842 **Figure Legends**

843 **Figure 1.** Diagrams of an inverted V-shaped osteotomy showing (A) a wedge of bone  
844 resected from the tibia beneath the lateral plateau in the shape of an inverted ‘V’ and (B)  
845 valgus correction and grafting of the resected wedged bone block into the triangular gap  
846 created beneath the medial plateau.

847

848 **Figure 2.** Preoperative planning

849 In the OW group, the hinge point ‘P’ is located at approximately 5 mm medial from the  
850 proximal tibiofibular joint (A). In the iV group, the hinge point ‘P’ is located at  
851 approximately at the medial edge of the tibial tubercle (B). First, a ‘line A’ is drawn  
852 from the centre of the femoral head through the point 65% lateral from the medial edge  
853 of the tibial plateau on the lateral tibial plateau. Second, a ‘line B’ is drawn from hinge  
854 point P to the centre of the talar dome. Then an arc C, the centre and the radius of which  
855 are the hinge point P and line B, respectively, is drawn so that the arc is across line A.  
856 Next, a ‘line D’ is drawn from hinge point P to the crossing point between line A and arc  
857 C. The angle (alpha) formed between line B and line D provides the correction angle.

858

859 **Figure 3.** Pre- and post-operative radiographs in OW-HTO.

860 (A) Anteroposterior radiograph before OW-HTO. (B) Lateral radiograph before OW-  
861 HTO. (C) Anteroposterior radiograph after OW-HTO. (D) Lateral radiograph after  
862 OW-HTO. Dotted line: Osteotomy line

863

864 **Figure 4.** Pre- and post-operative radiographs in iV-HTO.

865 (B) Anteroposterior radiograph before iV-HTO. (B) Lateral radiograph before iV-HTO.  
866 (C) Anteroposterior radiograph after iV-HTO. (D) Lateral radiograph after iV-HTO.  
867 Dotted line: Osteotomy line

868

869 **Figure 5.** Radiographic assessments.

870 (A) Hip–knee–ankle angle (HKA). The HKA was defined as the angle between the  
871 femoral mechanical axis and the tibial mechanical axis. (B) Femorotibial angle (FTA).  
872 The FTA was defined as the angle between the anatomical axis of the femoral shaft and  
873 the axis of the tibial shaft on the fibular side. (C) Mechanical axis of the lower limb. A  
874 mechanical axis line was drawn from the centre of the femoral head to the middle point  
875 of the proximal talar joint surface. The mechanical axis percentage was defined as the  
876 horizontal distance from the mechanical axis line to the medial edge of the tibial plateau  
877 (d), divided by the width of the tibial plateau (w). (D) Medial proximal tibial angle

878 (MPTA). The MPTA was defined as the angle between the proximal tibial joint line and  
879 the mechanical axis of the tibial shaft. (E) Posterior tibial slope (PTS). The PTS was  
880 defined as the angle between the line perpendicular to the mid-diaphysis of the tibia and  
881 the posterior inclination of the medial tibial plateau. (F) Entire leg length. The entire leg  
882 length was defined as the distance between the top of the femoral head and the centre of  
883 the tibial plafond. (G) The tibial length was defined as the distance between the centre of  
884 the proximal tibia and the centre of the tibial plafond. (H) Caton-Deschamps (CD) ratio.  
885 The CD ratio was defined as a ratio of the distance (x) between the inferior pole of the  
886 patella and the antero-proximal edge of the tibial plateau divided by the patellar length  
887 (y). (I) Insall-Salvati (IS) ratio. The IS ratio was defined as a ratio of the length of the  
888 patella tendon (the distance between the inferior pole of the patella and the tibial tubercle  
889 (x)) divided by the patellar length (y). (J) Tilting angle. The tilting angle was defined as  
890 the angle between the line intersecting the widest bony structure of the patella and the  
891 line tangentially passing the anterior surface of the femoral condyles. (K) Lateral shift  
892 ratio. The lateral shift ratio was defined as the ratio of the distances  $pp'/aa'$ .  $aa'$  is defined  
893 as the distance between the summits of the medial and lateral femoral condyles.  $pp'$  is  
894 defined as the distance between the summit of the lateral femoral condyle and the point  
895 where a line from the lateral edge of the patella perpendicular to the line that passes  
896 through the summits of the femoral condyles crosses that line.

897

898 **Figure 6.** The distance between the tibial tubercle and the trochlear groove (TT-TG).  
899 The TT-TG distance was measured from 2 superimposed CT slices, the distance was  
900 defined between the centre of the tibial tubercle (a) on one image and the trochlear groove  
901 perpendicular to the posterior femoral condyles (b) on a second image.

902

903 **Figure 7.** Follow-up examinations.

904 HTO, high tibial osteotomy; OA, osteoarthritis; SONK, spontaneous osteonecrosis of the  
905 knee.