

# Computer-assisted navigation decreases the change in the tibial posterior slope angle after closed-wedge high tibial osteotomy

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## Abstract

**Purpose** The purpose of the present study was to compare the change in tibial posterior slope angle (PSA) between patients treated via computer-assisted and conventional closed-wedge high tibial osteotomy (CWHTO). It was hypothesized that a decrease in the PSA would be less in the computer-assisted group than in the conventional group.

**Methods** Data on a total of 75 computer-assisted CWHTOs (60 patients) and 75 conventional CWHTOs (49 patients) were retrospectively compared using matched pair analysis. The pre- and postoperative mechanical axis (MA) and the PSA were radiographically evaluated. The parallel angle was defined as the angle between the joint line and the osteotomy surface. The data were compared between the two groups.

**Results** The postoperative radiographic MA averaged  $1.3^\circ \pm 2.6^\circ$  valgus in the computer-assisted group and  $0.3^\circ \pm 3.1^\circ$  varus in the conventional group. The change in PSA averaged  $-0.8^\circ \pm 0.9^\circ$  in the computer-assisted group and  $-4.0^\circ \pm 2.2^\circ$  in the conventional group. The parallel angle averaged  $0.2^\circ \pm 3.0^\circ$  in the computer-assisted group and  $6.2^\circ \pm 5.3^\circ$  in the conventional group.

**Conclusion** Computer-assisted CWHTO using four guide pins could avoid inadvertent change in the PSA. The navigation can be used in anticipation of decreasing the risk of change in the PSA in CWHTO, especially in patients whose preoperative PSA is small. The special attention

should be paid to locate the hinge axis acutely and to make the parallel proximal and distal osteotomy surfaces during CWHTO.

**Level of evidence** III.

**Keywords** Knee · High tibial osteotomy · Navigation · Tibial posterior slope angle

## Introduction

High tibial osteotomy (HTO) is a valuable surgical option for the treatment of unicompartmental medial osteoarthritic knees with varus deformity. Two basic techniques are available; these are medial open-wedge and lateral closed-wedge osteotomy, each of which has advantages and disadvantages. Both methods primarily address the coronal plane and affect the tibial posterior slope angle (PSA) [12, 19, 34]. A change in the PSA may influence knee kinematics and biomechanics, with rather negative consequences [17, 35]. It is known that changes in PSA trigger instability and excessive tibial translation of the sagittal plane and may also cause progression of osteoarthritis because of load concentration in particular regions [17]. The concern about the change in the PSA after HTO is important as much as effort to achieve the accurate correction angle. In previous studies, conventional open-wedge HTO (OWHTO) increased the PSA by  $3^\circ$ – $4^\circ$  [1, 13, 28, 31] and closed-wedge HTO (CWHTO) decreased the PSA by  $3^\circ$ – $5^\circ$  [12, 19]. Increasing the PSA after OWHTO is thought to be caused by the triangular configuration of the proximal tibia, posterolateral hinge axis, the symmetrical wedge opening of anterior and posterior cortices, incomplete osteotomy of posterior cortex and incomplete releasing of postero-medial soft tissue, and anterior placement of the fixative.

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Decreasing the PSA after CWHTO can be caused by the posteromedial hinge axis and asymmetrical wedge closing with nonparallel osteotomy surfaces.

A computer-assisted technique has recently been applied to increase the accuracy of correction of the angle in the coronal plane; the success of the HTO depends on accuracy of alignment [4, 9, 22, 25, 32, 37]. Many previous studies have analysed the accuracy, reliability, and repeatability of postoperative coronal alignment via computer-assisted HTO [4, 15, 16, 23]. However, it has not been well analysed whether the computer-assisted navigation can decrease the risk of change in the PSA.

In addition, it remains unclear whether the extent of the correction angle in the coronal plane significantly affects postoperative change in the PSA after HTO. Several authors have argued that the extent of change in the PSA was not significantly associated with the amount of coronal correction [30, 33]. Others reported that the change in PSA was statistically correlated with the correction angle [2, 5].

The purpose of the present study was to compare changes in the PSA after computer-assisted and conventional CWHTO. The second purpose was to evaluate whether the extent of the correction angle in the coronal plane affects postoperative change in the PSA after HTO. It was hypothesized that a decrease in the PSA would be less in the computer-assisted group than in the conventional group. To our knowledge, this is the first study to compare the change in the PSA between the computer-assisted and conventional CWHTO.

## Materials and methods

Data were prospectively obtained from patients who underwent computer-assisted CWHTO between 2005 and 2014. The Vector Vision® CT-free navigation system (version 1.1, Brainlab, Heimstetten, Germany) was used to examine patients. The inclusion criteria for the study were medial compartment osteoarthritis associated with a varus deformity  $>10^\circ$ . The exclusion criteria for HTO were (1) flexion contracture of  $>15^\circ$ ; (2) flexion angle of  $<90^\circ$ ; (3) lateral compartment osteoarthritis (Kellgren–Lawrence grade 3–4); (4) lateral tibial subluxation of  $>1$  cm. A total of 140 computer-assisted CWHTO (130 patients) were collected. Seventy-five knees treated via conventional CWHTO between 1994 and 2006, using the same inclusion criteria, could be retrospectively reviewed (the control group). The patients of conventional CWHTO and computer-assisted CWHTO were selected by the matched pair method on age, gender body mass index (BMI), right and left, mechanical alignment prior to surgery, the correction angle, and the preoperative PSA. A miniplate staple (U&I®, Uijeongbu-si,

**Table 1** Demographics of computer-assisted and conventional group in closed-wedge high tibial osteotomy

	Computer-assisted group	Conventional group	<i>p</i> value
Operation period	2005–2014	1994–2006	
Number of patients	60	49	
Number of knees	75	75	
Age (year)	57.7 ± 6.7	60.3 ± 7.0	n.s.
Gender (female/male)	55/5	45/4	n.s.
Body mass index (kg/m <sup>2</sup> )	24.9 ± 2.5	24.3 ± 3.7	n.s.
Right/left	34/41	36/39	n.s.

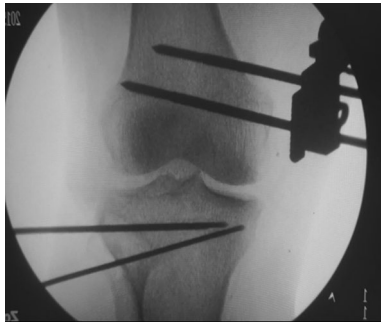
*n.s.* not significant

Korea) was used as a fixative in both groups [3]. Eventually, 75 knees were evaluated in each group after a computer-assisted patient and a control patient were matched. The demographics of both groups are given in Table 1. There was no significant difference between the two groups in terms of age, gender, body mass index, or operative side.

There was difference in the follow-up period between two groups since the operation was performed in a different period. However, the authors made an effort to diminish the bias through comparing the preoperative and postoperative 3 months radiograph for each patient.

## Surgical technique and rehabilitation

Computer-assisted and conventional CWHTO was performed as described previously [4]. The standard registration procedure for computer-assisted CWHTO was applied according to the requirements of the system used. The postoperative mechanical axis percentage (MA %) was targeted to be 62 % in both groups [36]. All the computer-assisted and conventional CWHTOs were done by one surgeon. The same surgical technique and rehabilitation protocol were used for both groups, with the exception of the navigation system and the numbers of used guide pins on the proximal and distal osteotomy surfaces. In computer-assisted group, a precalibrated navigation drill guide was used to place two K-wires in the proximal plane of the osteotomy. Another two pins were inserted in the distal plane of the osteotomy, in the same manner (Fig. 1). The anterior and posterior heights of the wedge were rendered symmetrical using this four-pin technique. In the conventional group, one pin was inserted in the proximal plane of the osteotomy and the other one in the distal plane, under fluoroscopic guidance, to determine the correction angle and wedge size upon preoperative radiographic planning. These values were intraoperatively confirmed using a cable method [26].



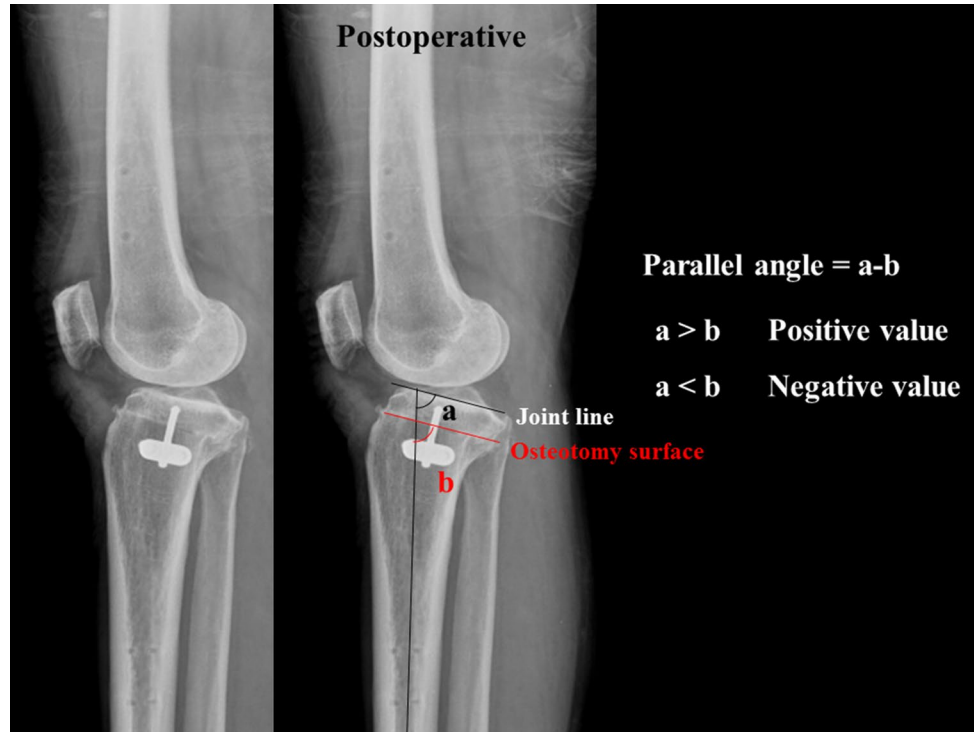
**Fig. 1** Computer-assisted closed-wedge high tibial osteotomy using four guide pins. A precalibrated navigation drill guide is used to place two K-wires in the proximal plane of the osteotomy and two K-wires in the distal plane. Parallel placement of the proximal and distal K-wires and accurate orientation of the hinge axis are confirmed via C-arm imaging. The image intensifier shows that the inserted two pins for each proximal and distal osteotomy planes look like one pin because they are completely parallel

### Radiographic evaluation

Radiographic measurements of coronal alignment were taken from full-length weight-bearing anteroposterior radiographs of the leg, including the hip, knee, and ankle (i.e. orthoroentgenograms) to assess the MA. For

orthoroentgenogram, the feet were neutrally positioned in a consistent alignment for acquisition of films because the rotational variation would affect the accuracy of measurement. The MA for coronal plane alignment was defined as the angle between the femoral and tibial mechanical axes.

Lateral radiographs of the knee were obtained and reviewed to assess the PSA [4]. The PSA was measured with reference to the medullary canal. The reference line for the PSA was a line connecting the centre of the medullary canal to positions 10 and 20 cm distal to the tibial plateau. The PSA was defined as the angle between the perpendicular line of reference and a line connecting the anterior and posterior borders of the medial tibial plateau. The parallel angle between the joint line and the osteotomy surface was evaluated on lateral knee radiographs and was defined as the angle between the medial joint surface of the proximal tibia and the osteotomy surface (Fig. 2). High-quality pre- and postoperative radiographs were obtained for all patients, and all measurements were taken using a standardized picture-acquiring communication system (Infinit, Seoul, Korea) [14]. The radiographic measurements were taken on a 24 in. LCD monitor in portrait mode using PACS software. The software package allowed the investigator to detect the bisecting point of any region on the femur or tibia and to measure angles between any



**Fig. 2** Radiographic measurement of the parallel angle. The parallel angle was measured on lateral radiographs of the knee and is defined as the angle between the medial joint surface of the proximal tibia

and the osteotomy surface ( $a-b$ ). A *positive value* indicates that the osteotomy surface has a steep slope in comparison with the joint line ( $a > b$ )

two lines drawn on the digital image. It allowed the accurate measurement above one decimal. Postoperative radiographic evaluation was performed using the same method after 3 months, at which time all patients could stand with complete weight-bearing. To reduce observation bias, two independent investigators repeatedly taken all radiographic measurements. The intra- and inter-observer reliabilities of all measurements were assessed by calculating intra-class correlation coefficients (ICC) [27], which were >0.8 for all measures, confirming both intra- and inter-observer reliability.

Ethical approval for the study was obtained by our institutional review board (Kyung Hee University Hospital, KMC IRB 1540-07).

### Statistical analysis

The pre- and postoperative MAs were compared between the computer-assisted and conventional groups (Student's *t* test). The pre- and postoperative PSA and changes in the PSA were compared between both groups (Student's *t* test). The proportions of PSA inliers and the parallel angles were compared between both groups (Chi-squared test). The inlier of change in PSA, or the inlier of parallel angle, was defined as changes in PSA or the parallel angle of  $\pm 4^\circ$  (these were regarded as the clinically significant values) [6]. Correlations between pre- and postoperative PSA were explored in both the computer-assisted and conventional groups (Pearson's correlations obtained via linear regression). The correlations between the extent of the correction angle and the change in PSA were compared between the groups (Pearson's correlation). Intraclass correlation coefficient (ICC) values >0.8 were considered to be very strong, values 0.6–0.8 moderately strong, values 0.3–0.6 fair, and values <0.3 weak [8]. Statistical analysis was performed

using SPSS for Windows (version 18.0; SPSS Inc., Chicago, IL, USA). A *p* value <0.05 was considered to indicate statistical significance in all analyses.

The present study was adequately powered to be able to detect a significant difference ( $\alpha < 0.05$ ) with 80 % power. That degree of power would be achieved with study groups comprising at least 70 knees in computer-assisted CWHTO group and 70 knees in conventional CWHTO group.

## Results

### Measurement of the MA in the coronal plane

In the computer-assisted group, the mean MA prior to osteotomy was  $8.9^\circ \pm 2.8^\circ$  varus, as measured on the radiographs. The mean postoperative MA was  $1.3^\circ \pm 2.6^\circ$  valgus. The correction angle of MA was  $10.2^\circ \pm 2.7^\circ$ . In the conventional group, the mean radiographic MA was  $9.2^\circ \pm 4.4^\circ$  varus preoperatively and  $0.3^\circ \pm 3.1^\circ$  varus postoperatively. The correction angle of MA was  $8.9^\circ \pm 3.5^\circ$ . There was significant difference in postoperative MA between the computer-assisted and conventional groups ( $p = 0.035$ ; Table 2).

### Measurement of the PSA and parallel angle in the sagittal plane

The mean preoperative PSA was  $10.7^\circ \pm 2.2^\circ$ , and the mean postoperative PSA was  $9.9^\circ \pm 2.2^\circ$  in the computer-assisted group. The mean preoperative PSA was  $10.7^\circ \pm 3.9^\circ$ , and the mean postoperative PSA was  $6.7^\circ \pm 4.6^\circ$  in the conventional group (Table 2). The PSA decreased postoperatively in both groups, but the extent of change was significantly greater in the conventional

**Table 2** Comparison of radiographic measurements between computer-assisted and conventional group in closed-wedge high tibial osteotomy

	Computer-assisted group	Conventional group	<i>p</i> value
Mechanical axis ( $^\circ$ ) <sup>a</sup>			
Preoperative	Varus $8.9 \pm 2.8$	Varus $9.2 \pm 4.4$	n.s.
Postoperative	Valgus $1.3 \pm 2.6$	Varus $0.3 \pm 3.1$	0.035
Correction of MA ( $^\circ$ )	$10.2 \pm 2.7$	$8.9 \pm 3.5$	n.s.
Tibial posterior slope angle			
Preoperative	$10.7 \pm 2.2$	$10.7 \pm 3.9$	n.s.
Postoperative	$9.9 \pm 2.2$	$6.7 \pm 4.6$	0.003
Change in tibial posterior slope angle <sup>b</sup>	$-0.8 \pm 0.9$	$-4.0 \pm 2.2$	0.003
Parallel angle	$0.2 \pm 3.0$	$6.2 \pm 5.3$	<0.001

n.s. not significant

Negative values mean tibial posterior slope decreases postoperatively

<sup>a</sup> Mechanical axis, angle between the femoral and tibial mechanical axis

<sup>b</sup> Change in tibial posterior slope angle, postoperative tibial posterior slope angle–preoperative tibial posterior slope angle

**Table 3** Distribution of change in tibial posterior slope angle between computer-assisted and conventional group in closed-wedge high tibial osteotomy

Change in tibial posterior slope angle (°)	Computer-assisted group (no.)	Conventional group (no.)
<-4	0	31
-4 to -2	5	38
-2 to 0	60	6
0 to 2	9	0
2 to 4	1	0
>4	0	0
Total	75	75

**Table 4** Distribution of parallel angle between computer-assisted and conventional group in closed-wedge high tibial osteotomy

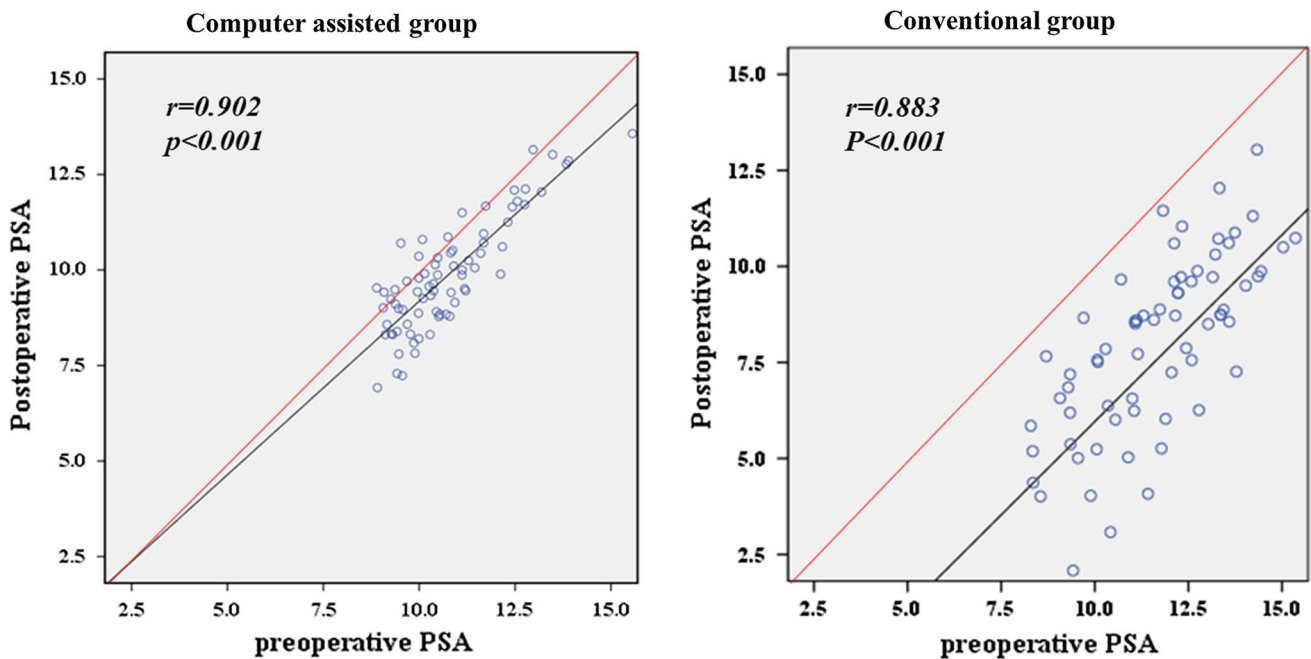
Parallel angle (°)	Computer-assisted group (no.)	Conventional group (no.)
<-4	6	3
-4 to -2	9	0
-2 to 0	17	0
0 to 2	16	3
2 to 4	20	19
>4	7	50
Total	75	75

group (0.8° vs. 4.0°,  $p = 0.003$ ). The proportion of inlier of change in PSA was greater in the computer-assisted group (100 vs. 58.7 %,  $p < 0.001$ ; Table 3). The postoperative parallel angle was significantly smaller in the computer-assisted group than in the conventional group (0.2° vs. 6.2°,  $p < 0.001$ ; Table 2). The proportion of parallel angle inliers was greater in the computer-assisted group (82.7 vs. 29.3 %,  $p < 0.001$ ; Table 4).

Positive correlations between pre- and postoperative PSA values were evident in both the computer-assisted and conventional groups. The ICC values showed that the pre- and postoperative correlations were strong in the both group ( $r = 0.852$  vs.  $0.883$ ;  $p < 0.001$ ; Fig. 3). We found no correlation between the extent of angular correction in the coronal plane and change in the PSA in the sagittal plane in either group ( $r = 0.024$ ,  $p = \text{n.s.}$ ;  $r = 0.224$ ,  $p = \text{n.s.}$ ).

**Discussion**

The most important finding of the present study is that the change in PSA after CWHTO was significantly less in the computer-assisted compared to the conventional group when the preoperative deformity was similar between the two groups. The mean postoperative MA was closer to the targeted correction angle in computer-assisted group, and the associated standard deviation was smaller (Table 2).



**Fig. 3** Correlation between pre- and postoperative tibial posterior slope angle (PSA). A positive correlation is evident. The intraclass correlation coefficients show that the correlation was stronger in the

computer-assisted group (0.852 vs. 0.883). The PSA decreased postoperatively in all knees of the conventional group



A reduction in the PSA after conventional CWHTO can be explained by considering the geometry of the proximal tibia, which is triangular in shape, with the apex directed anteriorly. If wedge excision is not absolutely lateral or perpendicular to the anatomical axis, more bone may be removed anteriorly from the anterolateral part of the proximal tibia during wedge resection, possibly causing an unwanted reduction in the PSA. If the wedge is asymmetrically closed (thus, the anterior and posterior height differs), a change in the PSA will be unavoidable. Such an effect may be enhanced by subsequent compression during loading and weight-bearing [11, 19]. Residual posterolateral support from the proximal tibiofibular syndesmosis is another possible explanation of a reduction in the PSA after CWHTO [21]. Kaper et al. [21] were of the view that a reduction in the PSA after CWHTO was significantly associated with patellar baja. The three-dimensional orientation of the wedge is important, because asymmetrical closing of the wedge could introduce an unwanted secondary alteration of the PSA in the sagittal plane. About determination of the hinge axis of CWHTO, it should be targeted to be placed on the medial cortex and perpendicular in coronal plane. And the proximal osteotomy plane should be parallel to the joint line. There have been reports that posteromedial placement of the hinge axis causes greater changes in PSA [12, 19]. However, it is difficult to accurately control the position of the hinge axis using the conventional technique [19, 24, 29]. The navigation feature of CWHTO allows the surgeon to accurately control the position of the hinge axis and to render the angle between the proximal and distal pairs of pins parallel (as in our four-pin technique; Fig. 1). In earlier CWHTO series, the average PSA difference was  $-3.8^\circ$  in the study of Brouwer et al. [7] and  $-4.9^\circ$  in that of Hohmann et al. (Table 5) [19]. In the present study, the average PSA changes were  $-0.8^\circ \pm 0.9^\circ$  in the computer-assisted group and  $-4.0^\circ \pm 2.2^\circ$  in the conventional group ( $p < 0.001$ ). The average parallel angle was  $0.2^\circ \pm 3.0^\circ$  in the former group and  $6.2^\circ \pm 5.3^\circ$  in the latter ( $p < 0.001$ ). We suggest that accurate placement of the hinge axis under

navigation guidance, and appropriate orientation of the wedge using the four-pin technique, reduces the potential for changes in the PSA.

The second important finding is that there was no correlation between the extent of correction in the coronal plane and the change in PSA in the sagittal plane. Jacobi et al. [20] reported that a larger correction angle increased not only the mean value of the PSA change, but also the variability thereof, during computer-assisted open-wedge HTO. A significant flexion contracture in severe osteoarthritis and disruption of the lateral cortical hinge were associated with an increased change in the PSA. The absence of any correlation between the correction angle and a change in PSA has also been noted in several previous studies [13, 30, 33]. It is likely that the changes in the PSA can be affected by several factors and the unwanted alterations in the PSA can be created by errors committed during surgery. We suggest that the computer-assisted technique usefully minimizes various possible surgical errors and increases the accuracy of both sagittal and coronal alignment.

A limitation of the present study is that a prospective cohort (the computer-assisted group) was compared with a retrospective consecutive cohort (the conventional group). However, a matched pair analysis was performed to compare the two groups with similar preoperative demographics. An optimal study would include a large prospective, randomized controlled trial to achieve significant results. The second limitation is the difference in operative period between the two groups. Computer-assisted CWHTO was performed later than was conventional CWHTO (Table 1), and the good radiographic results obtained in the former group may be attributable, in part, to progress on a learning curve. However, the surgeon had more than 10 years of experience with conventional CWHTO and had treated over 120 knees prior to 1994. The time of the learning curve for the conventional technique lays before the period in which the first cohort was treated. It was hypothesized that navigation during CWHTO would improve the accuracy and precision of the correction angle. The CWHTO was performed more frequently since software facilitating computer-assisted CWHTO became available in our hospital in 2005. This fact explains the differences in operative periods. However, the authors made an effort to diminish the influence of the difference in follow-up period through evaluating the preoperative and postoperative 3 months radiographs for each patient. The third limitation is that our patients differed from those who are candidates for HTO in Western countries; these differences must be considered when it is sought to extrapolate our findings to the other populations. The fourth limitation is that radiographic data on only the bony slope of the medial tibial plateau were collected. An earlier study measured the posterior slopes of the medial and lateral tibial plateaus

**Table 5** Change in tibial posterior slope angle after closed-wedge high tibial osteotomy in previous and present studies

References	Change in tibial posterior slope angle ( $^\circ$ )
Brouwer et al. [7]	-3.8
El-Azab et al. [13]	-2.7
Hoell et al. [18]	-5.3
Hohmann et al. [19]	-4.9
Conventional group in the present study	-4.0
Computer-assisted group in the present study	-0.8

separately, and the bony and meniscal slopes separately, via MRI [10]. However, the change in meniscal slope was equivalent to the change in the bony slope in the cited study [10]. Lastly, the clinical evaluations were not performed. However, the comparison of clinical results between the computer-assisted and conventional groups was difficult because of the big difference in the length of follow-up periods. Because the purpose of the study was to compare the difference in the amount of change in PSA according to operation techniques, the clinical evaluation could be suspended. Further studies are required to demonstrate that minimizing any change in PSA, via such navigation, affords clinical benefits.

The present study presents the clinical relevant finding that the navigation can be used in anticipation of decreasing the risk of change in the PSA in CWHTO, especially in patients whose preoperative PSA is small.

## Conclusion

Computer-assisted CWHTO with placement of four guide pins could avoid unwanted changes to the PSA because the hinge axis is accurately located and the joint line and osteotomy surface are parallel. The navigation can be used in anticipation of decreasing the risk of change in the PSA in CWHTO. The special attention should be paid to locate the hinge axis and to make the parallel proximal and distal osteotomy surfaces during CWHTO.

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