

# The ratio of mechanical axis shift to the correction angle differs in preoperative planning, but actual postoperative alignment is comparable between opening wedge and closed wedge high tibial osteotomy

**Takahiro Ogino**

Yokohama City University

**Ken Kumagai** (✉ [kuma.iphone@gmail.com](mailto:kuma.iphone@gmail.com))

Yokohama City University

**Shunsuke Yamada**

Yokohama City University

**Tomotaka Akamatsu**

Yokohama City University

**Shuntaro Nejima**

Yokohama City University

**Masaichi Sotozawa**

Yokohama City University

**Yutaka Inaba**

Yokohama City University

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## Research article

**Keywords:** high tibial osteotomy, opening wedge, closed wedge, mechanical axis shift, correction angle

**Posted Date:** March 13th, 2020

**DOI:** <https://doi.org/10.21203/rs.3.rs-17194/v1>

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**Version of Record:** A version of this preprint was published on October 12th, 2020. See the published version at <https://doi.org/10.1186/s12891-020-03703-6>.

# Abstract

**Background** The purpose of this study was to investigate the relationship between the bony correction angle and mechanical axis change and their differences between closed wedge high tibial osteotomy (CWHTO) and open wedge high tibial osteotomy (OWHTO). **Methods:** A total of 100 knees of 89 patients who underwent OWHTO (50 knees) or CWHTO (50 knees) were investigated. The femorotibial angle (FTA), % mechanical axis deviation (MAD), % anatomical tibial axis deviation (ATAD), % mechanical tibial axis deviation (MTAD), mechanical medial proximal tibial angle (mMPTA), and joint line convergence angle (JLCA) were measured on preoperative and postoperative radiographs. The amount of change from preoperative to postoperative in each measurement is represented as  $\Delta$ . **Results:** CWHTO resulted in a greater increase of  $\Delta(\%MTAD - \%ATAD)/\Delta mMPTA$  than OWHTO ( $P < 0.05$ ), and a greater decrease of  $\Delta JLCA/\Delta mMPTA$  than OWHTO ( $P < 0.05$ ). However, no significant difference was found in the  $\Delta \%MAD/\Delta mMPTA$  between CWHTO and OWHTO. When the osteotomy was planned with the same bony correction angle, %MA passed more laterally in OWHTO than in CWHTO ( $P < 0.05$ ). These results suggested a lesser valgus bony correction ratio due to greater medial shift of the tibial axis and greater valgus compensation of the soft tissue in CWHTO compared to OWHTO. **Conclusions:** The ratio of mechanical axis shift to the correction angle differed in preoperative planning, but postoperative alignment was comparable between opening wedge and closed wedge high tibial osteotomy.

## Introduction

High tibial osteotomy (HTO) is an established procedure to correct lower limb alignment and to reduce the mechanical force on the affected compartment. Proper overcorrection provides pain relief and subsequent improvement of knee function [1, 2]. Two commonly used procedures for HTO are the lateral closed wedge and the medial opening wedge osteotomy. Excellent clinical outcomes have been reported with both techniques, although there are potential advantages and disadvantages [3–5].

Several studies have reported significant differences between CWHTO and OWHTO in radiological variables, including posterior tibial slope, leg length change, and patellar height [6–8]. However, to date, there have been no reports of a comparison between CWHTO and OWHTO regarding the relationship between the correction angle at the osteotomy site and shift of the mechanical axis. A wedged bone is removed from the lateral cortex in CWHTO, and the proximal tibia is offset laterally. In contrast, the lateral cortex is retained in OWHTO. The amount of lateral shift of the proximal tibia from the anatomical axis differs between CWHTO and OWHTO [9]. That is, the effect of the same bony correction angle on mechanical axis deviation is presumed to differ between CWHTO and OWHTO.

The purpose of this study was to investigate the relationship between the bony correction angle and mechanical axis change and their differences between CWHTO and OWHTO. It was hypothesized that CWHTO shows greater medial shift of the tibial axis and less mechanical axis change than OWHTO with the same bony correction angle.

## Materials And Methods

A total of 100 knees of 89 patients who underwent HTO between 2011 and 2015 were investigated. The inclusion criterion was painful osteoarthritis (OA) localized to the medial compartment of the knee. Exclusion criteria were OA of the lateral compartment, flexion contracture greater than 15°, or a history of inflammatory arthritis, joint infection, or immunosuppressive therapy. The decision for either technique was made preoperatively according to the correction angle. OWHTO was performed in 50 knees of 46 patients with a correction angle of 15° or less, and CWHTO was performed in 50 knees of 43 patients with a correction angle of more than 15°. Demographic data are shown in Table 1. This retrospective case series study was approved by the institutional review board at Yokohama City University (#B180200061).

Table 1  
Demographic data

	CWHTO	OWHTO
Number of patients (knees)	43 (50)	46 (50)
Male	15 (17)	14 (16)
Female	28 (33)	32 (34)
Age (years)	63.9 ± 22.9	64.5 ± 21.5
Body mass index (kg/m <sup>2</sup> )	25.4 ± 10.1	24.6 ± 6.2
OA grade* 2/3/4 (knees)	7/25/19	33/11/6
* OA grade modified from Ahlback's classification		

## Surgical procedure and postoperative management

The amount of angular correction was planned preoperatively aiming to achieve tibiofemoral anatomical valgus of 10° in a one-leg standing radiograph postoperatively.

OWHTO was performed using an anteromedial approach under fluoroscopic guidance. The osteotomy was started 35 mm below the medial articular surface of the tibia. An oblique osteotomy was performed from the medial cortex to the upper third of the proximal tibiofibular joint using biplanar technique, leaving the tibial tuberosity intact. The osteotomized gap was gradually opened and filled with two wedged blocks of  $\beta$ -TCP with 60% porosity (Osferion®, Olympus Terumo Biomaterials. Corp., Tokyo, Japan) and fixed with TomoFix (DePuy Synthes, Zuchwil, Switzerland).

CWHTO was performed using an anterolateral approach under fluoroscopic guidance after fibular osteotomy. The osteotomy was started 30 mm below the lateral articular surface of the tibia. The proximal osteotomy was performed parallel to the tibial plateau, and the distal osteotomy was performed obliquely toward the hinge point of the medial cortex, with a flange to leave the insertion of the patellar

tendon with a distal fragment. The osteotomy gap was closed and fixed with an OWL plate (Mizuho Ikkakogyo Co., Ltd., Tokyo, Japan).

Patients started a postoperative rehabilitation program including isometric quadriceps and range-of-motion exercises the day after surgery. In CWHTO, a non-weight-bearing regimen was prescribed for 2 weeks, followed by partial weight-bearing exercise, and full weight-bearing exercise was permitted 3 weeks postoperatively. In OWHTO, a non-weight-bearing regimen was prescribed for 1 week, followed by full weight-bearing exercise. Casts or supportive devices were never applied in both procedures.

## Radiographic assessment

Anteroposterior radiographs of the knee were taken in the standing position preoperatively and 1 month postoperatively. Limb alignment was expressed as the femorotibial angle (FTA), measuring the lateral angle between the femoral axis and the tibial axis [2]. The joint line convergence angle (JLCA) was measured as the angle formed between a line tangent to the distal femoral condyle and the proximal tibial plateau [10]. Full-length anteroposterior radiographs of the lower limb were taken in the standing position preoperatively and 1 month postoperatively. The mechanical medial proximal tibial angle (mMPTA) was measured as the medial angle formed between the tibial mechanical axis and the knee joint line of the tibia [11]. The percentage of mechanical axis deviation (%MAD) was defined as the ratio of the distance from the medial border of the proximal tibia to the mechanical axis of the lower limb to the width of the proximal tibia [12]. The percentage of anatomical tibial axis deviation (%ATAD) was defined as the ratio of the distance from the medial border of the proximal tibia to the passing point of the anatomical axis on the tibial surface to the width of the proximal tibia (Fig. 1). The percentage of mechanical tibial axis deviation (%MTAD) was defined as the ratio of the distance from the medial border of the proximal tibia to the passing point of the mechanical axis on the tibial surface to the width of the proximal tibia (Fig. 1). The amounts of changes from preoperative to postoperative in the FTA, JLCA, mMPTA, %MAD, %ATAD, and %MTAD were defined as  $\Delta$ FTA,  $\Delta$ JLCA,  $\Delta$ mMPTA, % $\Delta$ MAD, % $\Delta$ ATAD, and % $\Delta$ MTAD, respectively. Fujifilm OP-A® software (Fujifilm, Co Ltd, Tokyo, Japan) was used for all measurements.

## Statistical Analysis

Statistical analysis was carried out using BellCurve for Excel version 2.21 (Social Survey Research Information, Tokyo, Japan). The Mann-Whitney U test was used to compare the measurements between two different HTO procedures. The Wilcoxon signed-rank test was used to compare the measurements in preoperative planning between different HTO procedures in the same subjects. An adjusted p value < 0.05 was considered significant. A power calculation indicated that a sample size of 47 in each osteotomy procedure could detect differences with an effect size of 0.2, with 5% probability of a type I error and power of 80%. The intra- and inter-rater reliabilities of radiographic measurements were assessed by calculating intraclass correlation coefficients (ICC).

## Results

# Radiographic measurements

Pre- and postoperative measurements of FTA, %MAD, %ATAD, %MTAD, %MTAD - %ATAD, mMPTA, and JLCA are summarized in Table 2. There were significant differences in preoperative FTA, %MAD, and JLCA between CWHTO and OWHTO ( $p < 0.05$ ). The mean FTA and JLCA decreased postoperatively, and the mean %MA and mMPTA increased postoperatively in both CWHTO and OWHTO ( $p < 0.05$ ). The mean postoperative %ATA decreased in CWHTO ( $p < 0.05$ ), which was significantly smaller than in OWHTO ( $p < 0.05$ ). The mean postoperative %MTAD - %ATAD increased in CWHTO ( $p < 0.05$ ), significantly greater than in OWHTO ( $p < 0.05$ ).

Table 2  
Radiographic measurements

		CWHTO	OWHTO
FTA (°)	Preop.	187.3 ± 8.7†	181.5 ± 5.5
	Postop.	167.8 ± 8.8*	167.8 ± 6.2*
%MAD	Preop.	-10.9 ± 32.3†	12.3 ± 25.1
	Postop.	72.3 ± 32.5*	75.6 ± 24.0*
%ATAD	Preop.	52.1 ± 14.4	50.5 ± 6.1
	Postop.	40.1 ± 11.8*†	49.7 ± 6.0
%MTAD	Preop.	49.8 ± 7.2	49.7 ± 5.6
	Postop.	51.2 ± 6.6	49.9 ± 6.4
%MTAD-%ATAD	Preop.	-2.4 ± 6.9	-0.8 ± 5.7
	Postop.	11.0 ± 7.6*†	0.2 ± 2.5
mMPTA (°)	Preop.	82.1 ± 9.9	83.8 ± 6.8
	Postop.	97.9 ± 8.1*	96.6 ± 8.6*
JLCA (°)	Preop.	6.0 ± 8.0†	3.6 ± 4.4
	Postop.	3.6 ± 5.4*	3.0 ± 3.0*
* P < 0.05 vs Pre-op † P < 0.05 vs CWHTO			
FTA femorotibial angle, %MAD percentage of mechanical axis deviation, %ATAD percentage of anatomical mechanical axis deviation, %MTAD percentage of tibial mechanical axis deviation, mMPTA mechanical medial proximal tibial angle, JLCA joint line convergence angle, Preop. preoperative, Postop. postoperative			

Differences between preoperative and postoperative radiographic measurements are summarized in Table 3. Magnitudes of  $\Delta$ FTA,  $\Delta$ %MAD,  $\Delta$ %ATAD,  $\Delta$ %MTAD,  $\Delta$ (%MTAD - %ATAD), and  $\Delta$ JLCA were

significantly greater in CWHTO than in OWHTO ( $P < 0.05$ ).

Table 3  
Differences between pre- and postoperative radiographic measurements

	CWHTO	OWHTO	P value
$\Delta$ FTA ( $^{\circ}$ )	$-19.6 \pm 10.6$	$-13.9 \pm 7.1$	$< 0.001$
$\Delta$ %MAD	$83.2 \pm 37.2$	$63.3 \pm 26.2$	$< 0.001$
$\Delta$ %ATAD	$-12.0 \pm 11.4$	$-0.8 \pm 4.8$	$< 0.001$
$\Delta$ %MTAD	$1.4 \pm 5.1$	$0.2 \pm 4.8$	0.05
$\Delta$ (%MTAD-%ATAD)	$13.4 \pm 9.5$	$1.0 \pm 4.1$	$< 0.001$
$\Delta$ mMPTA ( $^{\circ}$ )	$15.8 \pm 7.8$	$12.8 \pm 6.8$	$< 0.001$
$\Delta$ JLCA ( $^{\circ}$ )	$-3.2 \pm 3.8$	$-0.9 \pm 3.1$	$< 0.001$
FTA femorotibial angle, %MAD percentage of mechanical axis deviation, %ATAD percentage of anatomical mechanical axis deviation, %MTAD percentage of tibial mechanical axis deviation, mMPTA mechanical medial proximal tibial angle, JLCA joint line convergence angle			

The ICCs for inter-and intra-rater reliabilities were all  $> 0.8$ , ranging from 0.88 to 0.97 for all radiological measurements, indicating good reliability.

## Effects of bony correction on mechanical axis shift and joint line inclination

To assess the effects of the bony correction angle on mechanical axis shift and joint line inclination, the ratios of  $\Delta$ %MAD,  $\Delta$ JLCA, or  $\Delta$ (%MTAD - %ATAD) to  $\Delta$ mMPTA were compared between CWHTO and OWHTO (Table 4). CWHTO resulted in a greater decrease of  $\Delta$ JLCA/ $\Delta$ mMPTA than OWHTO ( $p < 0.05$ ), and a greater increase of  $\Delta$ (%MTAD - %ATAD)/ $\Delta$ mMPTA than OWHTO ( $p < 0.05$ ). However, no significant difference was found in the  $\Delta$ %MAD/ $\Delta$ mMPTA between CWHTO and OWHTO.

Table 4  
Relationship between  $\Delta$ MPTA and  $\Delta$ %MA,  $\Delta$ JLCA, or  $\Delta$ (%MTA-%ATA)

	CWHTO	OWHTO	P value
$\Delta$ %MAD/ $\Delta$ mMPTA	5.4 $\pm$ 4.3	4.9 $\pm$ 0.6	0.129
$\Delta$ JLCA/ $\Delta$ mMPTA	-0.19 $\pm$ 0.28	-0.05 $\pm$ 0.22	< 0.001
$\Delta$ (%MTA-%ATA)/ $\Delta$ mMPTA	0.94 $\pm$ 0.83	0.06 $\pm$ 0.36	< 0.001
%MAD percentage of mechanical axis deviation, %ATAD percentage of anatomical mechanical axis deviation, %MTAD percentage of tibial mechanical axis deviation, mMPTA mechanical medial proximal tibial angle, JLCA joint line convergence angle			

## Comparison of alignment changes between CWHTO and OWHTO in preoperative planning

To assess the difference in alignment change between CWHTO and OWHTO in preoperative planning, the cases who underwent CWHTO surgery were re-planned for CWHTO and OWHTO with the same correction angle according to the actual bony correction angle ( $\Delta$ mMPTA) (Fig. 3). Changes of %MAD and mMPTA were significantly greater in OWHTO than in CWHTO (Table 5).

Table 5  
Comparison of alignment changes between CWHTO and OWHTO in the preoperative planning by the same correction angle

	CWHTO	OWHTO	P value
$\Delta$ %MAD	61.6 $\pm$ 16.5	66.2 $\pm$ 17.9	< 0.001
$\Delta$ mMPTA	14.6 $\pm$ 3.8	15.4 $\pm$ 4.0	< 0.001
%MAD percentage of mechanical axis deviation, mMPTA mechanical medial proximal tibial angle			

## Discussion

The most important finding of the present study was that CWHTO had a greater medial shift of the tibial axis and a lower valgus bony correction ratio than OWHTO. However, actual postoperative alignment was comparable between the two procedures due to greater valgus compensation of soft tissue in CWHTO.

OWHTO and CWHTO are the two most frequently used techniques for correcting varus deformity. CWHTO is conventionally used for valgus correction with various fixative devices [1, 13, 14], and excellent long-term results have been reported [2, 15]. This method involves invasive operative procedures, since fibular osteotomy and muscle detachment of the tibialis anterior are required. The procedure is technically demanding and has inherent complications, including fractures, neurovascular injuries, compartment syndrome, venous thrombosis, infection, delayed union or nonunion, instability, recurrent varus deformity,

and valgus overcorrection [16]. OWHTO has been recognized as less invasive, safe, and easy to perform, and it has recently become more commonly used with the development of the rigid plate fixator [17, 18]. This technique avoids many of the pitfalls of CWHTO and facilitates intraoperative adjustment of the final knee alignment. However, the differences between the two techniques are still controversial [6–8, 19], and there is still no precise indication for either technique. Ferner et al. introduced a unique algorithm for choosing between the HTO procedures, OWHTO or CWHTO, based on torsional deformity, patellar height, and length discrepancy [20]. In the clinical setting, the extent of the correction angle should be one of the most important factors for choosing either OWHTO or CWHTO. The correction angle is limited to 15° or less in OWHTO [21], whereas a larger correction is allowed in CWHTO. Either technique should be selected in the borderline cases with a correction of around 15°.

Lateral tibial condylar offset is created by HTO, and some transposition to the bony axis occurs. In general, CWHTO has greater lateral shift of the proximal tibia from the anatomical axis than OWHTO [9, 22], which often makes it difficult to perform revision total knee arthroplasty [23]. Lateral tibial condylar offset also affects the amount of the correction angle in the different osteotomy procedures. Lateral tibial condylar offset after CWHTO resulted in medial shift of the tibial shaft including the ankle joint. In addition, leg length shortening also affects the medial shift of the ankle joint. In contrast, the medial shift of the tibial shaft was relatively small, and leg length was extended after OWHTO. Thus, the mechanical axis of the lower limb on the tibial surface would pass more laterally in OWHTO than in CWHTO, when the osteotomy is performed with the same bony correction angle (Fig. 3). If the same target alignment is preoperatively planned in both OWHTO and CWHTO, CWHTO requires a greater correction angle than OWHTO.

The present study demonstrated that the mean postoperative lower limb alignment in OWHTO was comparable with that in CWHTO, although the other parameters were significantly different. Dugdale et al. have shown that total varus angulation of the OA knee was composed of three potential components: femorotibial geometric alignment, narrowing or loss of the osteocartilaginous complex, and separation of the lateral joint due to slack ligamentous and soft tissues [24]. Lower limb alignment after HTO is affected by soft tissue balance, as well as the bony correction angle [25, 26]. Unexpected valgus overcorrection may be due to large preoperative JLCA in both OWHTO [10] and CWHTO [27]. A larger correction angle also affects overcorrection [25]. In the present series, CWHTO showed a greater ratio of JLCA change to the bony correction angle than OWHTO. Although the preoperative planning of CWHTO is likely to indicate undercorrection compared to that of OWHTO with the same correction angle, in fact, larger postoperative change of the JLCA compensates the valgus angle in CWHTO, and total alignment is equivalent in both osteotomy procedures.

This study has several limitations. The follow-up time of 1 month was short. The current series assessed the early postoperative change of knee alignment. The indication for either HTO technique was determined preoperatively according to the correction angle. This may affect the amount of change in JLCA.



## Conclusion

The ratio of mechanical axis shift to the correction angle differed in preoperative planning, but postoperative alignment was comparable between OWHTO and CWHTO.

## Abbreviations

FTA: femorotibial angle; %MAD: percentage of mechanical axis deviation; %ATAD: percentage of anatomical mechanical axis deviation; %MTAD: percentage of tibial mechanical axis deviation; mMPTA: mechanical medial proximal tibial angle; JLCA: joint line convergence angle

## Declarations

### Acknowledgements

Not applicable.

### Author's contributions

Study design: KK. Study conduct: TO, KK, SY, TA, SN, MS, and YI. Data interpretation: TO, KK, SY, TA, SN, MS, and YI. Drafting manuscript: TO, KK, and YI. KK takes responsibility for the integrity of the data analysis

### Funding

This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### Availability of data and materials

The datasets used and/or analyzed during current study are available from the corresponding author on reasonable request.

### Ethics approval and consent to participate

This study was approved by the institutional review board at Yokohama City University (#B180200061). Informed consent was obtained from all individual participants included in the study.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no conflict of interest.

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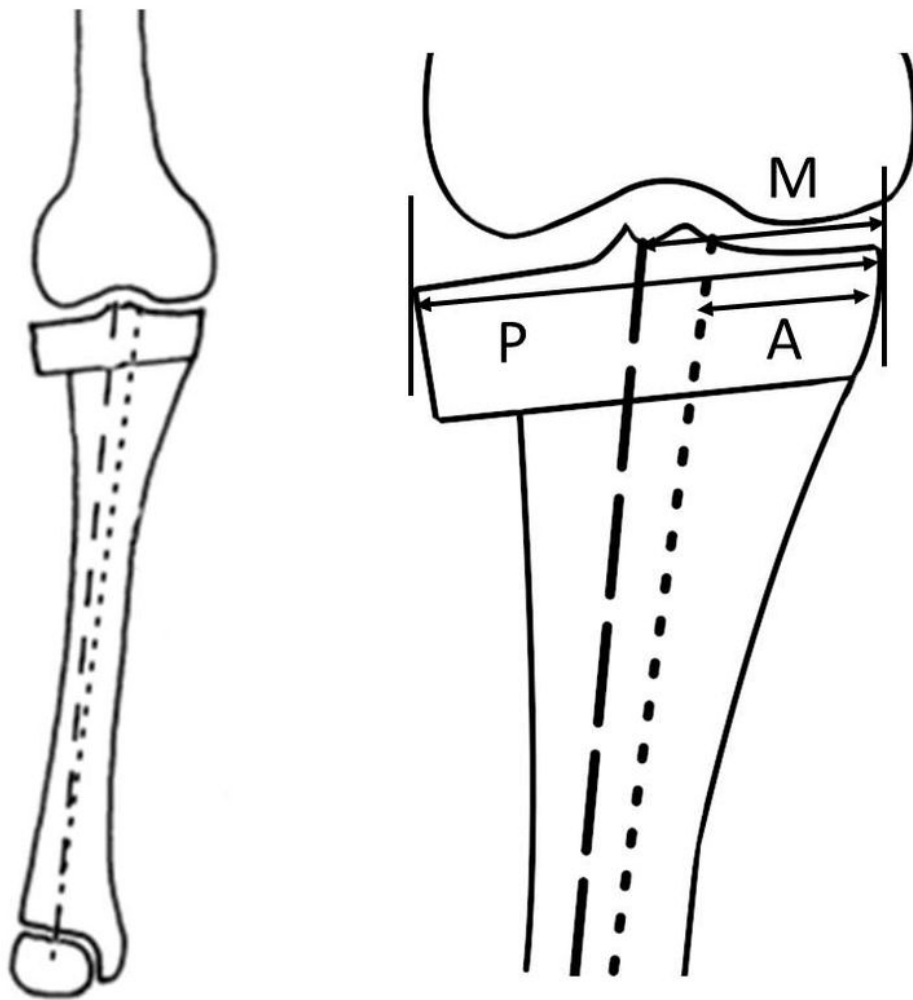
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## Figures

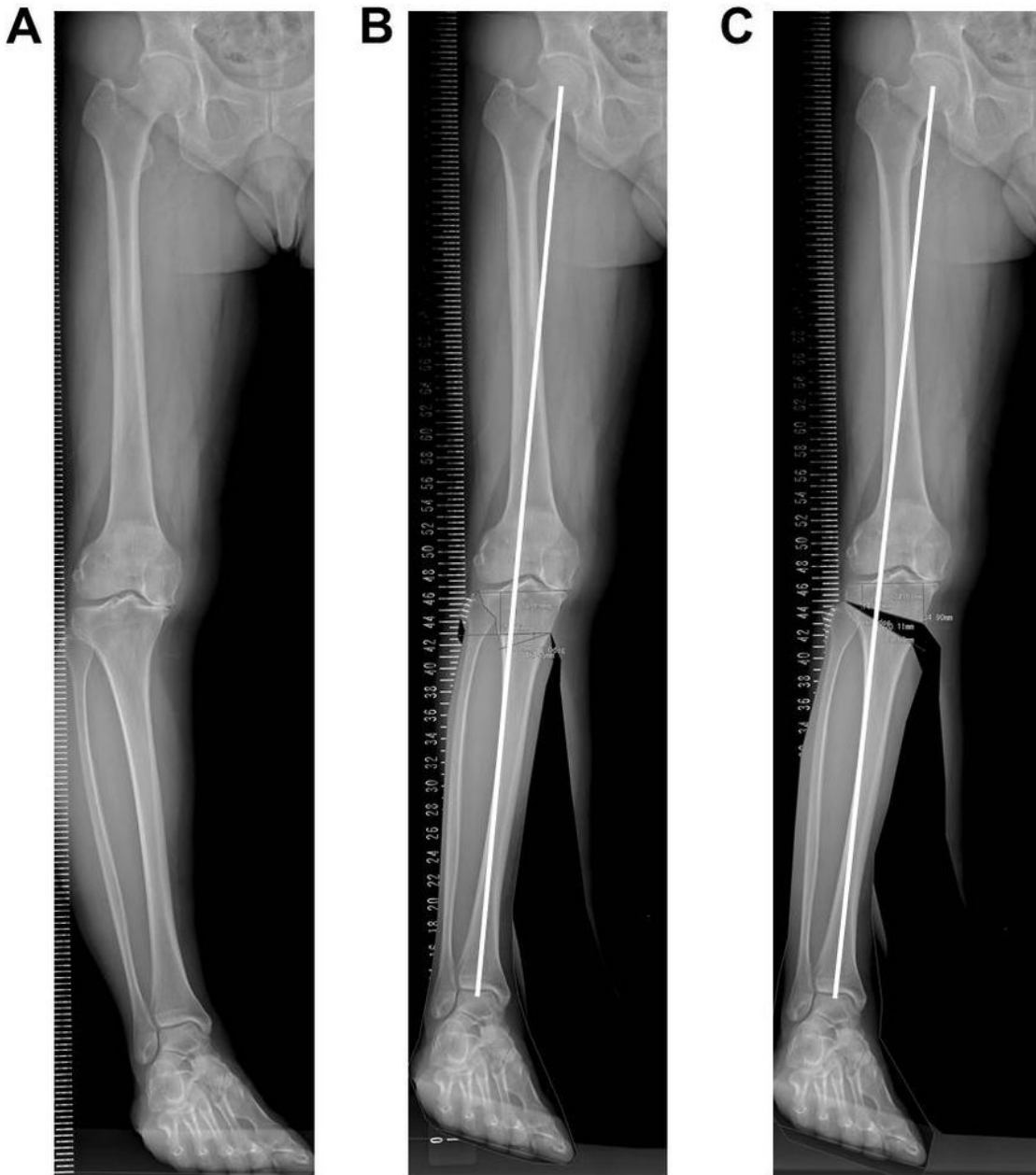


- Anatomical Tibia Axis (ATA)
- Mechanical Tibia Axis (MTA)

**Fig. 1**

**Figure 1**

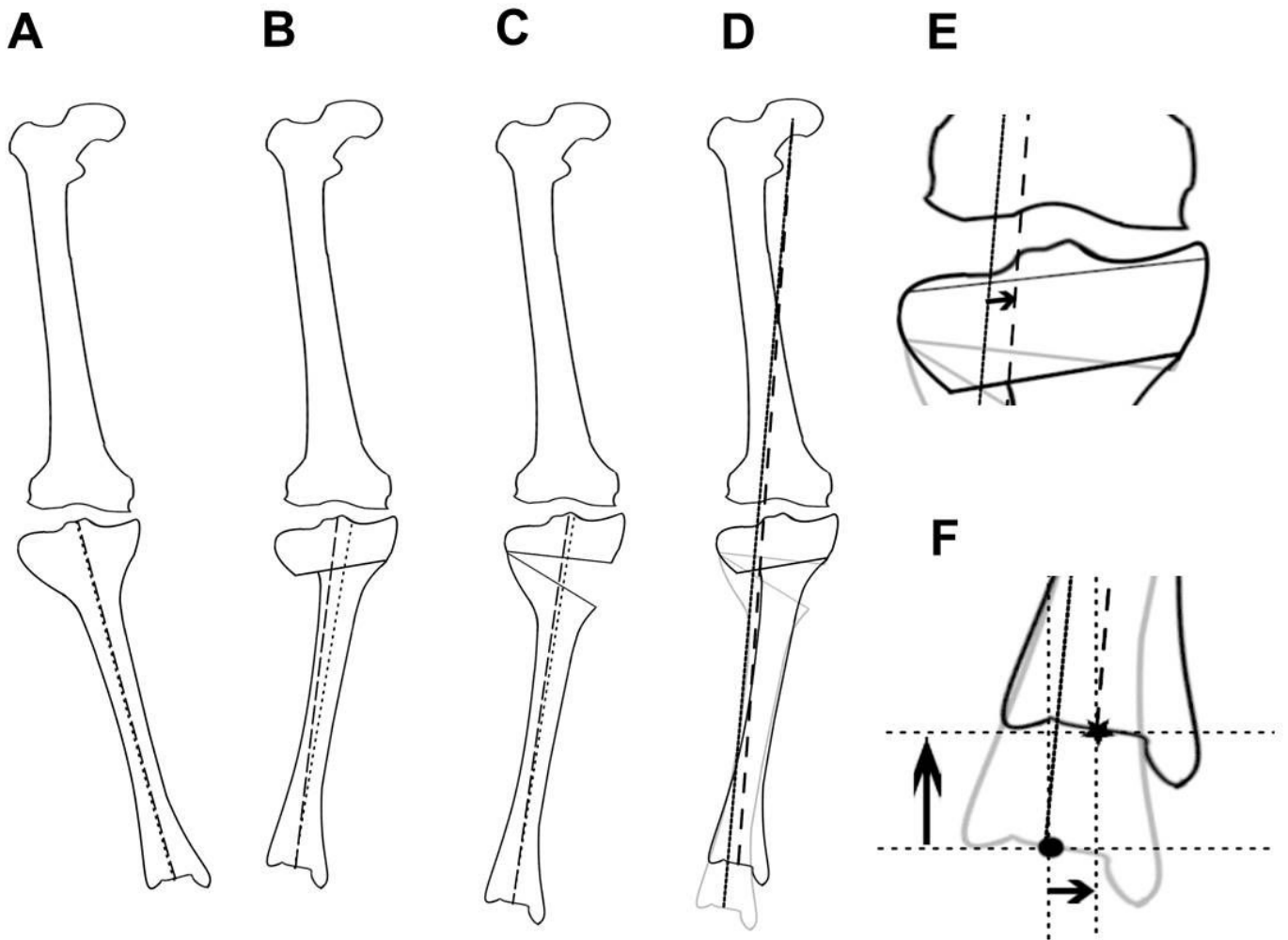
Definition of tibial axis deviation. The percentages of anatomical tibial axis deviation (%ATAD) and mechanical tibial axis deviation (%MTAD) are defined as the ratio of the distance from the medial edge of the proximal tibia to the passing points of the anatomical axis and mechanical axis on the tibial surface (A and M) and to the width of the proximal tibia (P), respectively. A percentage is calculated by multiplying this ratio by 100%.



**Fig. 2**

**Figure 2**

Preoperative planning for OWHTO or CWHTO with the same correction angle. The osteotomies are planned with a bony correction angle of 15° in a case with %MA of 0 (A), expecting %MA of 60 for CWHTO (B) and 68 for OWHTO (C).



**Fig. 3**

**Figure 3**

A schematic comparison between CWHTO and OWHTO in the position of the mechanical tibial axis including the center of the ankle joint after osteotomies with the same bony correction angle. Illustrations show preoperative status (A), CWHTO (B), OWHTO (C), and an overlay of the two procedures (D). The mechanical axis after CWHTO passes more medially than that after OWHTO (E). The center of the ankle after CWHTO (dot) is positioned more medially and proximally than that after OWHTO (asterisk) (F).