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# Change in limb length after high tibial osteotomy using computer-assisted surgery: a comparative study of closed- and open-wedge osteotomies

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## Abstract

*Purpose* Limb length changes were evaluated after closed- and open-wedge high tibial osteotomies (HTOs) using computer-assisted surgery.

*Methods* A total of 78 closed- and 30 open-wedge HTOs were performed. The changes in limb length were evaluated on a navigation system and radiographs. The correction angle was defined as the difference between the pre and postoperative mechanical axis on the navigation system. The change in limb length with respect to the correction angle was analyzed.

*Results* Following the closed-wedge HTOs, the mean changes in limb length based on the navigation system and radiographs were $-1.3 \pm 1.9$ and $-1.3 \pm 10.7$ mm, respectively, versus $6.2 \pm 2.6$ and $7.8 \pm 2.9$ mm after the open-wedge HTOs. The mean correction angle was $11.6 \pm 3.2°$ for closed-wedge HTOs and $11.5 \pm 1.9°$ for open-wedge HTOs. The correction angle did not affect the change in limb length after closed-wedge HTO, while the larger the correction angle required, the greater the increase in limb length after open-wedge HTO.

*Conclusions* The change in limb length was negligible after closed-wedge HTO, while the limb length was increased slightly after open-wedge HTO. The possibility of limb lengthening must be considered carefully when determining whom to perform open-wedge HTO on, especially when a large correction angle is required.

*Level of evidence* III.

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## Introduction

A high tibial osteotomy (HTO) is a common surgical option for osteoarthritic knees with varus deformity [14, 26, 29, 39]. There are two basic techniques: lateral closed-wedge osteotomy and medial open-wedge osteotomy [5, 6, 12, 16, 22, 24]. Neither technique is consistently superior to the other because each has its own advantages and disadvantages [1, 7, 8, 11, 19, 30]. Generally, a closed-wedge HTO tends to shorten the tibial length, while an open-wedge HTO tends to lengthen it [17, 18, 33]. However, only one clinical study has directly evaluated the pre and postoperative limb lengths in HTO for osteoarthritic knees [31].

In closed-wedge HTO, the metaphyseal bone loss of the proximal tibia shortens the tibial length. However, correcting varus deformity has the effect of lengthening the limb because the femur and tibia are collinear after HTO [15, 25]. In open-wedge HTO, the medial opening of the proximal tibia lengthens the tibia [18, 33]. However, the increased overall limb length does not seem to be as great as the amount of medial cortical opening in our experience. This was thought to be because the postoperative mechanical axis is restored in slight valgus. We wondered how variables such as the correction angle or change in the tibial posterior slope angle (PSA) affect the change in limb length in the two types of HTO.

Occasionally, conventional full-leg radiographs are inaccurate for measuring the limb length because of lower extremity rotation and knee flexion; the incidence in image parallax and the amount of magnification may also contribute to the measurement error [5, 10, 38]. The navigation system used during the HTO can measure the overall limb

length accurately to calculate the distance between the hip and ankle centers in three-dimensional space.

Therefore, this study evaluated pre and postoperative limb lengths determined using the navigation system and radiographs after HTO with computer-assisted surgery (CAS) and compared the change in limb lengths between the closed- and open-wedge HTO groups. We also analyzed the change in limb length with respect to the correction angle and change in PSA between the two groups.

The hypothesis was that the overall limb length of the corrected extremity does not change much after closed-wedge HTO because the effect of extremity realignment on limb length counterbalances the effect of tibial shortening caused by the metaphyseal bone loss of the proximal tibia. After an open-wedge HTO, the overall limb length would increase within a certain range.

## Materials and methods

Seventy-eight closed-wedge HTOs were performed in 74 patients between 2005 and 2010 using the CT-free navigation system (Vector Vision® ver. 1.1, BrainLAB, Heimstetten, Germany) for medial compartment osteoarthritis of the knee and genu varum deformity. A miniplate staple (U&I®, Uijeongbu-si, Korea) [4] was used to fix the osteotomy site. Thirty open-wedge HTOs were performed in 28 patients between July 2005 and January 2007 using the same navigation system with the same inclusion criteria. A Puddu plate (Arthrex, Naples, Florida, USA) was used to fix the osteotomy site. Informed consent was obtained from all patients before the review and no patient refused to participate in this study. The mean age was $58.8 \pm 7.5$ years in the closed-wedge HTO group and $56.3 \pm 7.5$ years in open-wedge HTO group. The demographics of the two HTO groups are shown in Table 1.

### Measurements using the navigation system

Under navigational guidance, the mechanical axis (MA), mechanical axis percent (MA%), and limb length were

**Table 1** Demographics of closed- and open-wedge HTO

|  | Closed-wedge HTO | Open-wedge HTO |
|---|---|---|
| Number of cases | 78 | 30 |
| Number of patients | 74 | 28 |
| Age (year) | $58.8 \pm 7.5$ | $56.3 \pm 7.5$ |
| Femal:male | 70:4 | 25:2 |
| Right:left | 45:33 | 11:19 |
| Body mass index (kg/m$^2$) | $25.0 \pm 2.5$ | $25.1 \pm 2.7$ |

*HTO* high tibial osteotomy

measured before and after the osteotomy. The MA% was measured navigationally as the percentage by which the mechanical axis bisects the total width of the tibia [15, 25, 27]. The pre and postoperative limb lengths obtained with the navigation system were compared. The correction angle was defined as the difference between the pre and post-operative MA with the navigation system. In this study, the navigational data were measured and recorded to one decimal place in the navigation system.

### Radiographic evaluation

Radiographically, the MA, MA%, and limb length were measured from full-length, weight-bearing, anteroposterior radiographs of the leg, including the hip, knee, and ankle (an orthoreontgenogram) [13]. Radiographic images for the limb length were taken on a cassette with ruler. The posterior slope angle of the tibia (PSA) was measured from a true lateral view of the knee. The radiographs were taken the day before and 2 weeks after surgery. The images were transferred digitally and manipulated with a picture-acquiring communication system (PACS) [37].

The radiographic results were evaluated pre and post-operatively to determine the MA, MA%, PSA, and limb length. The MA for coronal plane alignment was defined as the angle between the femoral and tibial mechanical axes. The MA% was defined as the percentage by which the mechanical axis bisects the total width of the tibia [23]. The tibial intramedullary reference line of the PSA was defined as the line connecting the center of the medullary canal 10 and 20 cm distal to the tibial plateau. The PSA was defined as the angle formed by the line perpendicular to the reference line and the medial tibial plateau [36]. The limb length was defined as the distance between the hip center and ankle center. The radiographic magnification of the limb length measurements obtained radiographically was corrected. By standardizing the radiograph method, the distance between the radiograph source and the patient's bone was 245 cm, and the distance between the radiograph source and cassette film was 260 cm. Therefore, the corrected limb length was calculated by multiplying the radiographically measured limb length × 245/260. The corrected limb lengths on the radiographs could be directly compared with the measurements made with the navigational guidance system. The correction angle was defined as the difference between the pre and postoperative MA. The change in PSA was the difference between the pre and postoperative PSA. A positive value indicated an increase in PSA. The change in limb length referred to the difference between the pre and postoperative limb lengths; a positive value indicated an increase in limb length.

To reduce any observation bias, two independent investigators made all of the radiographic measurements.

**Table 2** Pre and postoperative limb lengths between closed- and open-wedge HTO

| | Closed-wedge HTO | Open-wedge HTO | $p$ value |
|---|---|---|---|
| **Navigation** | | | |
| Pre-HTO (mm) | 701.9 ± 34.2 | 692.2 ± 28.1 | |
| Post-HTO (mm) | 700.6 ± 34.0 | 698.4 ± 27.8 | |
| Change in limb length (mm) | −1.3 ± 1.9 | 6.2 ± 2.6 | <0.001 |
| **Radiograph** | | | |
| Pre-HTO (mm) | 705.3 ± 34.8 | 690.9 ± 27.1 | |
| Post-HTO (mm) | 704.0 ± 34.2 | 698.7 ± 27.0 | |
| Change in limb length (mm) | −1.3 ± 10.7 | 7.8 ± 2.9 | <0.001 |

*HTO* high tibial osteotomy

The intra and interobserver reliabilities of the measurements were assessed using the intraclass correlation coefficient. In this study, the intraclass correlation coefficients for all measurements were greater than 0.8 for the intra and interobserver reliabilities.

### Statistical analysis

The pre and postoperative limb lengths obtained using the navigation system and radiographs were compared using Pearson's correlation analysis. The change in limb length was compared in the closed- and open-wedge HTO groups (Student's $t$ test). The change in limb length according to the type of HTO was analyzed in terms of the correction angle and change in PSA using Pearson's correlation analysis. Statistical analyses were performed using SPSS version 16.0 (SPSS, Chicago, IL), and $p$ values <0.05 were considered statistically significant.

### Clinical evaluation

The median follow-up period was 3.4 (range 1–5.7) years. The clinical results were evaluated in terms of the American Knee Society knee and function scores [20] and range of motion (ROM). Any complications were recorded.

### Surgical method

A senior surgeon performed all of the HTO procedures. Both types of HTO were performed as described previously [3, 5, 8, 21]. The size of the wedge of the lateral closing or medial opening required to achieve the desired correction was determined using navigation guidance. The postoperative MA% based on the navigation system was 62%. The far cortical hinge was tailored to be 3 mm in order to help the surgeon to close or open the osteotomy surface easily. With this technique, there was no breakage at the far cortical hinge in this study. The tibial posterior slope could be fine-tuned in the planned osteotomy, keeping with the PSA measured on the preoperative radiograph. The same rehabilitation protocol was used for both types of HTO [3, 5, 8]:

straight leg raising exercises were started 3 days postoperatively; partial weight-bearing was started 1 week postoperatively; and full weight-bearing without crutches was started at 6–12 weeks based on the patient's condition.

## Results

The mean changes in limb length based on the navigation system and radiographs were −1.3 ± 1.9 and −1.3 ± 10.7 mm respectively after the closed-wedge HTO versus 6.2 ± 2.6 and 7.8 ± 2.9 mm, respectively, after the open-wedge HTO (Tables 2 and 3). There was a positive correlation between the pre and postoperative limb lengths using both the navigation system ($p < 0.001$) and radiographs ($p < 0.001$; Fig. 1).

The MA, MA%, and correction angle were measured using the navigation system and radiographs (Table 4). Based on the navigation system, the mean correction angle was 11.6 ± 3.2° after the closed-wedge HTO and 11.5 ± 1.9° after the open-wedge HTO (Table 4). The mean change in the PSA was −1.4 ± 0.6° after the closed-wedge HTO and 3.5 ± 1.3° after the open-wedge HTO (Table 4).

**Table 3** Number of knees in change in limb length between closed- and open-wedge HTO

| Change in limb length (mm) | Closed-wedge HTO | Open-wedge HTO |
|---|---|---|
| −8 to −6 | 1 | 0 |
| −6 to −4 | 2 | 0 |
| −4 to −2 | 32 | 0 |
| −2 to 0 | 25 | 0 |
| 0 to 2 | 13 | 2 |
| 2 to 4 | 5 | 5 |
| 4 to 6 | 0 | 6 |
| 6 to 8 | 0 | 10 |
| 8 to 10 | 0 | 6 |
| 10 to 12 | 0 | 1 |

*HTO* high tibial osteotomy

**Fig. 1** Pre and postoperative limb lengths on radiograph between closed- and open-wedge HTO



**Closed wedge HTO**
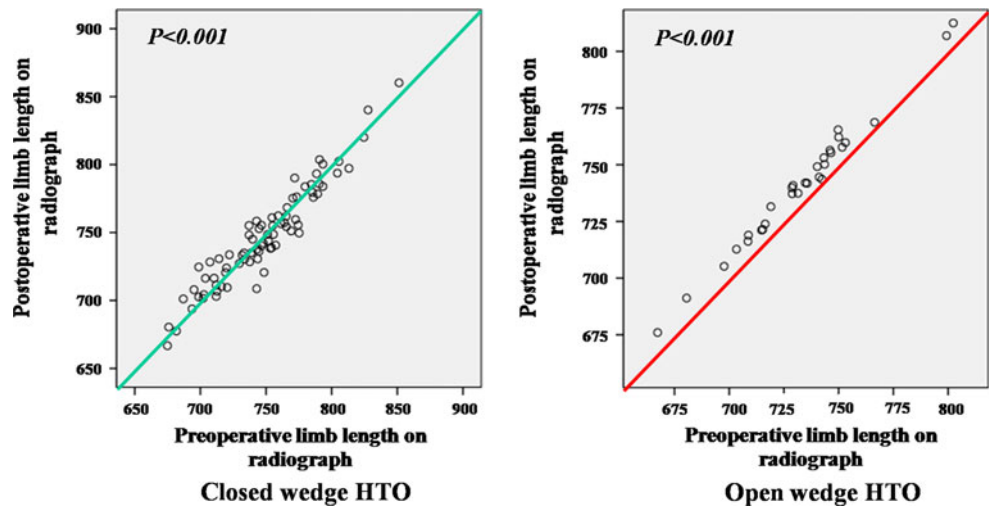
**Open wedge HTO**

**Table 4** Pre and postoperative mechanical axis, mechanical axis %, and tibial slope angle between closed- and open-wedge HTO

|  | Closed-wedge HTO | Open-wedge HTO |
|---|---|---|
| Navigation |  |  |
| Pre-HTO MA (°) | Varus 8.4 ± 2.8 | Varus 8.8 ± 2.7 |
| Post-HTO MA (°) | Valgus 3.5 ± 1.4 | Valgus 2.7 ± 2.1 |
| Correction angle (°) | 11.6 ± 3.2 | 11.5 ± 1.9 |
| Pre-HTO MA% (%) | 11.7 ± 7.9 | 14.8 ± 8.6 |
| Post-HTO MA% (%) | 62.2 ± 5.5 | 57.6 ± 9.2 |
| Radiograph |  |  |
| Pre-HTO MA (°) | Varus 7.7 ± 2.9 | Varus 9.8 ± 3.5 |
| Post-HTO MA (°) | Valgus 1.2 ± 2.7 | Valgus 4.0 ± 2.9 |
| Correction angle (°) | 8.9 ± 2.8 | 13.8 ± 2.5 |
| Pre-HTO MA% (%) | 14.9 ± 12.1 | 8.0 ± 15.4 |
| Post-HTO MA% (%) | 54.6 ± 12.2 | 64.6 ± 12.4 |
| Pre-HTO PSA (°) | 11.5 ± 3.3 | 13.1 ± 4.1 |
| Post-HTO PSA (°) | 10.2 ± 3.3 | 16.6 ± 4.6 |
| Change in PSA (°) | −1.4 ± 0.6 | 3.5 ± 1.3 |

*HTO* high tibial osteotomy, *MA* mechanical axis was defined as the angle between the femoral and tibial mechanical axes, *MA%* mechanical axis % (MA %) was defined as the percentage by which the mechanical axis bisects the total width of the tibia, *PSA* posterior slope angle of the tibia

For the closed-wedge HTOs, there was no correlation between the correction angle and change in limb length with the navigation system (n.s.; Fig. 2) or radiographs (n.s.). For the open-wedge HTOs, there was a significant correlation between the correction angle and change in limb length with the navigation system ($p = 0.001$; Fig. 2), while the correlation based on the radiographs was not significant.

In terms of the change in PSA, there was no correlation between the change in PSA and change in limb length on the radiographs with a closed-wedge HTO (n.s.; Fig. 3). With the open-wedge HTO, the change in PSA was negatively correlated with the change in limb length ($p = 0.053$; Fig. 3).

Clinically, the average knee score before a closed-wedge HTO was 74.4 and this improved to 87.6 at the last follow-up ($p < 0.001$). The average function score before the closed-wedge HTO was 73.2, which improved to 84.6 at the last follow-up ($p < 0.001$). The average ROM was 137.5° before the closed-wedge HTO and 140.4° at the last follow-up (n.s.). There was no significant difference in the clinical results between the closed- and open-wedge HTO. Regarding complications, there were three cases with a loss of correction >2° in each group.

## Discussion

The most important finding of this study was that the postoperative limb length decreased by an average of 1.3 mm after a closed-wedge HTO and increased by an average of 6.2 mm after an open-wedge HTO. There was no decrease greater than 8 mm after a closed-wedge HTO and no increase greater than 10.2 mm after an open-wedge HTO. The degree of limb length discrepancy that has clinical significance is controversial [32, 34, 35, 40, 41]. An acute limb length discrepancy >5–10 mm can lead to back pain and gait anomalies, although chronic adaptation is possible after a small change in limb length [32, 34, 35, 40, 41]. Considering this, the closed-wedge HTO resulted in a negligible change in limb length in our patients. The overall shortened limb length does not appear to be a disadvantage of a closed-wedge HTO, contrary to the generally accepted opinion [17, 18, 33]. The open-wedge HTO resulted in a slight increase in limb length, although the increase was much smaller than in previous studies [18, 31, 33].

**Fig. 2** Change in limb length according to correction angle on navigation system. There was a significant correlation between the correction angle and change in limb length after open-wedge HTO
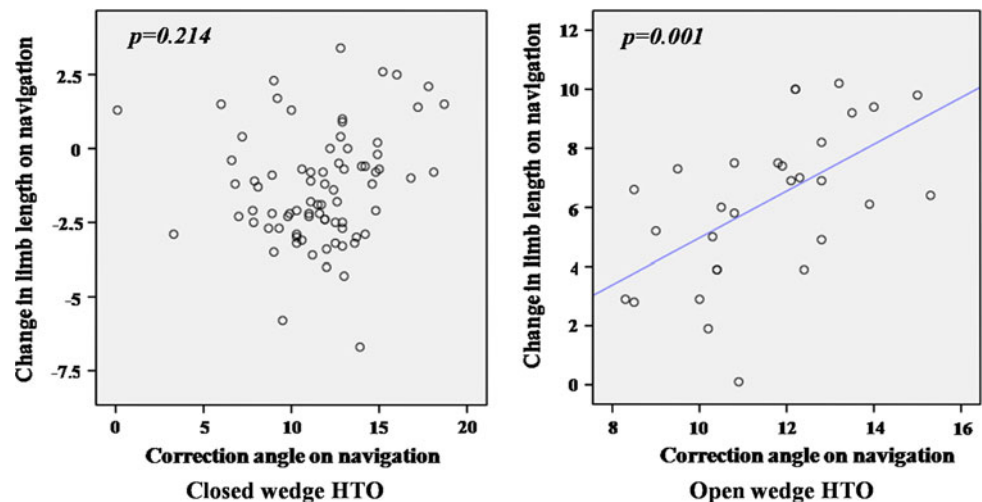


**Fig. 3** Change in limb length according to change in PSA on radiograph. There was significant correlation between the change in PSA or change in limb length after open-wedge HTO
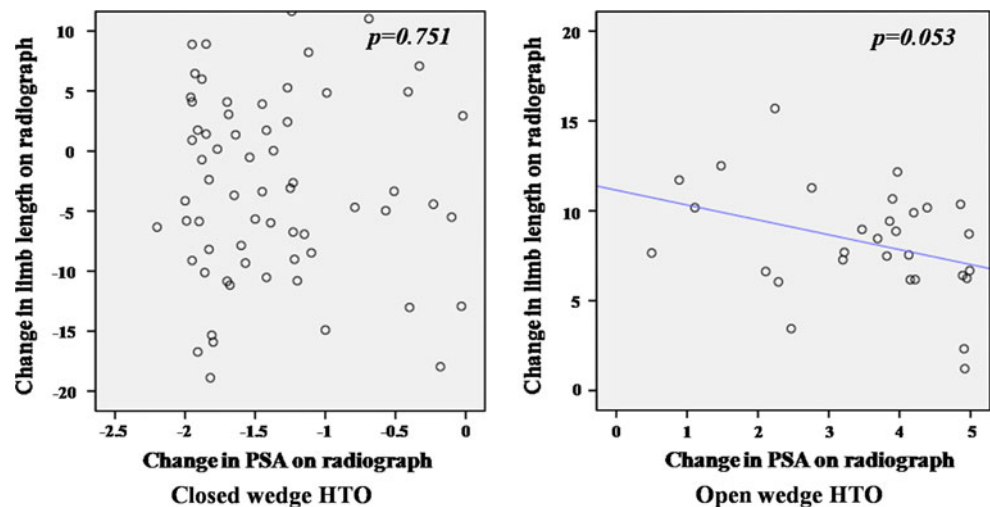


It was postulated that the postoperative limb length did not change as much as mathematically predicted because the effect of extremity realignment on limb length counterbalances the effect of tibial shortening after a closed-wedge HTO, and the shift in the weight-bearing axis from the medial opening cortex to the lateral plateau offsets the effect of tibial lengthening after an open-wedge HTO. Another reason was related to the different methods for measuring limb length, including the use of a navigation system and radiographic magnification.

The magnitude of radiographic magnification depends on various factors, including the length and girth of the limb, the distance from the radiograph source to the object, and the distance from the object to the cassette [13, 28]. In this study, the radiographic limb length measurements were corrected after considering the radiographic magnification and geometric principle of similar triangles. Therefore, the differences in the limb lengths with the navigation system and radiographs should be less than 4 mm (Table 2). When

comparing the differences in limb lengths between the navigation system and radiographs, the radiographic magnification should be considered.

Another purpose of the study was to analyze limb length changes according to the correction angle and change in PSA after closed- and open-wedge HTOs. Mathematically, the wedge width and amount of metaphyseal bone loss are correlated with the correction angle for closed-wedge HTOs [9, 10]. In our series, no correlation was found between the correction angle and change in limb length using either the navigation system or radiographs. We postulated that the effect of tibial shortening via metaphyseal bone loss of the proximal tibia is offset by other factors, the most important of which is extremity realignment. The average difference between the pre and postoperative PSA was only 1.4° after closed-wedge HTO using the navigation system in our series. This might be one reason why there was no significant correlation between the change in PSA and change in limb length after the closed-wedge HTOs.

There was a significant correlation between the correction angle and change in limb length on the navigation system after the open-wedge HTOs ($p = 0.001$). The greater the preoperative varus deformity and the greater the correction angle needed, the larger the medial cortical opening required and the greater the increase in limb length. Furthermore, the change in PSA was negatively correlated with the change in limb length after the open-wedge HTOs. The increased PSA after the open-wedge HTOs results in anterior translation of the tibia [2, 10]. It is thought that medial cortical opening of the proximal tibia would decrease the amount of limb lengthening.

Considering the clinical relevance of our data, the change in limb length after a closed-wedge HTO was negligible, and the shortening of the overall limb length does not appear to be a disadvantage of closed-wedge HTO, as has been generally accepted. A small change in limb length is possible after an open-wedge HTO in one leg and the patient can quickly adapt to the abrupt discomfort immediately after an open-wedge HTO. When a greater correction angle is required in an open-wedge HTO, the patient should be informed of the possibility of limb lengthening.

One limitation of this study was that it was not a randomized controlled trial, and our prospective cohort differed from those of patients who are candidates for HTO in Western countries. Another was the surgical limitation of the accuracy of percutaneous registration in HTO using the CAS. One criticism of the CAS registration technique is that it may not be accurate because of identifying the anatomical landmarks percutaneously. We marked the landmarks before registration after considering the surface anatomy carefully, and attempted to ensure that registration was accurate. Another weakness was the limited accuracy of the radiographic measurements. The difference between pre and postoperative limb length was small in comparison with the overall limb length in our study. Therefore, small changes in the projection angle and rotation or flexion of the knee could affect the radiographic measurements. Although computed tomography (CT) is accurate for measuring limb lengths, the radiation exposure and inability to obtain weight-bearing images limits the use of CT. Instead, we attempted to acquire consistent films in the neutral position and confirmed the intra and interobserver reliabilities of all measurements.

## Conclusion

In conclusion, there was a negligible change in limb length after closed-wedge HTO and limb length increased in every case by an average of 6.2 mm on the navigation system for the open-wedge HTO. The correction angle and change in PSA did not affect the change in limb length after the closed-wedge HTO. The greater the correction angle required in the open-wedge HTO, the greater limb length increases. An increased PSA after an open-wedge HTO had the effect of decreasing the amount of limb lengthening.

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