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Changes of knee joint and ankle joint orientations after high tibial osteotomy

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S U M M A R Y

Objective: We sought to determine (1) whether change in the tibial plateau inclination (TPI) after high tibial osteotomy (HTO) is different from change in the knee joint line orientation (KJLO) relative to the ground; (2) whether, in varus knee OA patients before and after HTO, these radiographic measures are different from those in normal control; and (3) whether the postoperative values of the TPI and KJLO relative to the ground are associated with short term clinical outcome scores after HTO.
Design: Fifty patients who underwent HTO and 75 normal controls were assessed with four radiographic measures. We compared the measures before HTO with those after HTO and with those of the normal controls, then examined associations between the postoperative radiographic measures and clinical outcome scores 1-year after HTO.
Results: After HTO, TPI increased 9.0°, whereas KJLO relative to the ground only increased 4.1°, with a compensatory change of the ankle joint line orientation. However, the postoperative KJLO relative to the ground in the HTO group was significantly different from that of the normal controls (mean difference, 4.9°; $P < 0.001$). In the multiple regression analyses, the postoperative radiographic measures were not associated with outcome clinical scores 1 year after HTO.
Conclusion: After HTO the relative KJLO changed significantly less than did the anatomical geometry of the proximal tibia. Although the KJLO after the HTO was still significantly different from that of normal knees, its value did not adversely affect clinical outcome scores 1 year after HTO.

Introduction

High tibial osteotomy (HTO) is a frequent realignment procedure for patients with symptomatic medial tibiofemoral (TF) osteoarthritis (OA) of the knee with varus malalignment[1–3]. Varus malalignment was reported to accelerate progression of medial compartment OA of the knee and to aggravate symptoms in such patients[4–6], therefore, HTO is considered to be a biomechanically sound joint preserving option for relatively younger patients with varus knee OA.

On the other hand, HTO has a potential biomechanical disadvantage; the procedure can lead to abnormal joint line orientation of the knee. HTO directly changes only the tibial geometry, thus the tibial plateau inclination (TPI) can become abnormally valgus which can eventually lead to abnormal knee joint line orientation (KJLO)[7–9]. Moreover, in a patient with medial TF OA, the traditionally recommended target alignment of the procedure is a few degrees of valgus mechanical alignment, i.e., slight overcorrection of the patient's limb alignment[10]. To the best of our knowledge, there is little information about effects of abnormal knee joint orientation on knee kinematics, functional outcomes, and long-term survivorship[7]. Given that major candidates for HTO are relatively younger and active patients, the potential adverse effects of the abnormal knee joint orientation caused by the procedure may be a concern for knee surgeons.[7–9]

However, changes of the proximal tibial geometry produced by HTO could theoretically influence the orientation of both joints directly connected to the osteotomy site, the knee and the ankle. In fact, we have observed that patients with preoperative varus malalignment frequently had an abnormal ankle joint line

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orientation (excessive lateral tilt) relative to the ground in the coronal plane; the excessive lateral tilt was reduced after HTO. Based on these theoretical considerations and observations, we speculated that the postoperative change of the KJLO relative to the ground may be diluted by the change of the ankle joint orientation relative to the ground. Consequently, the alteration of the relative KJLO after HTO would be smaller than the change in the TPI.

Therefore, this study sought to determine (1) whether change in the TPI after HTO is different from change in the KJLO relative to the ground; (2) whether, in varus knee OA patients before and after HTO, the TPI, and the knee- and the ankle joint line orientations relative to the ground differ from those of normal controls; and (3) whether the postoperative values of the TPI and KJLO relative to the ground are associated with short term functional outcome scores after HTO.

Method

Study subjects

For this study, we compared two study groups: (1) the HTO group included patients who underwent unilateral open-wedge HTO due to symptomatic varus knee OA and were followed for ≥1-year after HTO and (2) the control group included patients with asymptomatic and stable knees with no or minimal radiographic OA. We excluded patients who underwent bilateral HTO. We reviewed the medical records of 91 patients who underwent a unilateral open-wedge HTO performed by two surgeons in a single center between January 2008 and June 2012.

We excluded 41 patients in whom an HTO was performed due to diseases other than primary OA, such as ligament injuries (posterolateral corner injury of the knee and anterior cruciate ligament injury), developmental deformity of the knee, and malunion of a proximal tibial fracture. Finally, 50 eligible patients (50 knees) remained who underwent unilateral open wedge HTO due to symptomatic primary varus knee OA (Fig. 1). Our usual indications for HTO in patients with varus knee OA were (1) moderate (Kellgren–Lawrence grade 3) radiographic medial TF OA with varus malalignment and with an intact radiographic joint space at the lateral TF compartment; (2) the major component of the varus limb alignment was the proximal tibia not the distal femur; and (3) significant and disabling pain originating from the medial side of the knee that did not respond to >3 months of conservative measures. The HTO group included 38 women and 12 men with a mean age of 53 years (SD, 5.9; range, 33–63) and a mean body mass index (BMI) of 26.8 kg/m^2 (SD, 3.7; range, 20.2–35.0).

We enrolled 75 control subjects, 1.5 controls per HTO patient, matched individually by gender to the HTO group because alignment parameters may be influenced by gender[11]. Additionally, we included only control subjects >30 years of age as to reduce variation by age. From a database of 359 patients who underwent unilateral arthroscopic surgeries due to traumatic meniscal injuries and/or anterior cruciate ligament injuries between July 2010 and June 2012 we selected, in a retrograde order, 75 gender-matched and age-limited patients with contralateral asymptomatic and stable knees with no or minimal radiographic OA (Kellegren–Lawrence grade 0 or 1) as the control group (Fig. 1). The control group included 57 women and 18 men with a mean age of 44 years (SD, 9.0; range, 31–64) and a mean BMI of 24.1 kg/m^2 (SD, 3.4; range,18.6–37.4).

We estimated the sample size required to detect a 2° difference in the mean KJLO relative to the ground (considered to be clinically meaningful) between the controls and the post-HTO patients using an independent *t*-test. Based on the information obtained from a previous study[12], a minimum of 46 HTO patients and 69 control subjects, 1.5 controls per case, were required to detect this difference, with a the type I error of 0.05 and power of 0.8. This result verified the adequacy of the sample size of this study. This study was approved by the institutional review board of our hospital.

Radiographic evaluation

Four radiographic measures including (1) the mechanical TF angle, (2) the TPI, (3) the knee-, and (4) ankle joint line orientation relative to the ground were assessed using preoperative and postoperative 1-year standing full-limb anteroposterior (AP) radiographs in the HTO group and using preoperative standing full-limb AP radiographs in the controls. Standing full-limb AP radiographs were obtained on a 14- × 51-inch (36- × 130-cm) grid cassette at a source-to-image distance of 240 cm using a UT 2000 X-ray machine

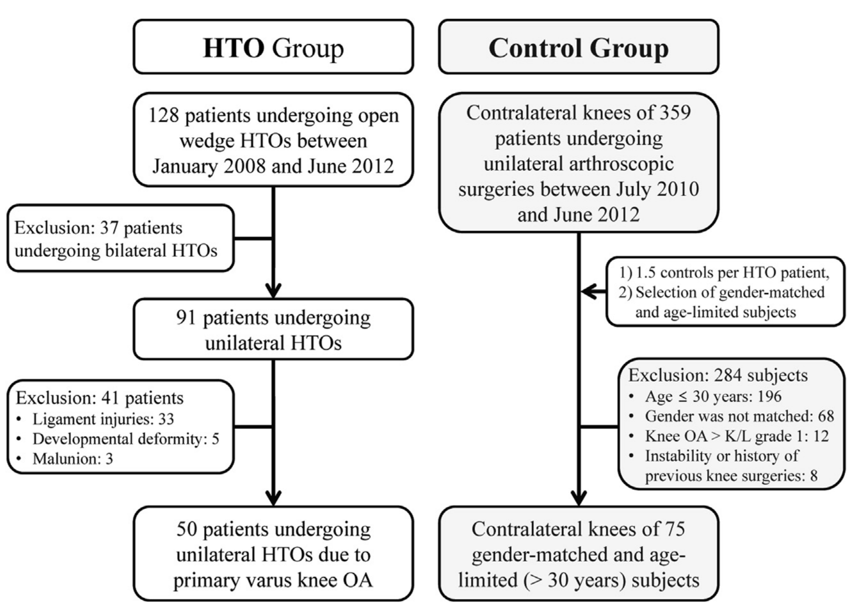

Fig. 1. Study subjects enrollment flowchart. HTO, High Tibial Osteotomy; OA, Osteoarthritis; K/L, Kellgren–Lawrence.

(Philips Research, Eindhoven, The Netherlands) set to 90 kV and 50 mA/s. To control the rotational position of the AP radiograph, foot rotation angle was held constant with a reference foot template on the platform of our plane radiographic system. In addition, the appropriate knee position (patellar facing forward) was confirmed using a preview monitor before final acquisition of the whole-limb AP radiograph. All radiographic images were digitally acquired using a picture archiving and communication system (PACS). Assessment was performed on a 24-inch (61-cm) monitor (U2412 M; Dell, Round Rock, TX, USA) in portrait mode using PACS software (Infinite, Seoul, Korea), which allowed the investigator to detect the bisecting point of any area on the femur or tibia and to measure the angle between any two lines drawn on the digital image. The minimum differences that the software could detect were 0.1° in angle and 0.1 mm in length.

The mechanical TF angle was defined as the angle formed by the intersection of the mechanical axes of the femur (the line from the femoral head center to the femoral intercondylar notch center) with the tibia (the line from ankle talus center to the center of the tibial spine tips); a negative value was given to knees in varus alignment [Fig. 2(A)].The TPI was computed as follows: (the angle between the mechanical axis of the tibia and the tangent to the subchondral plate of the tibia) − 90°; thereby a negative value was assigned to varus orientation of the tangent relative to the tibial mechanical axis [Fig. 2(B)]. The KJLO relative to the ground was defined as the angle between the line connecting the mid-points of the medial and lateral knee joint space, and a horizontal grid line on radiographs that was parallel to the floor; a negative value was given when the mid-joint space line tilted medially relative to the horizontal grid line [Fig. 2(C)]. The ankle joint line orientation relative to the ground was defined as the angle between the tangent to the subchondral plate of the talus and the horizontal grid line on radiographs; a negative value was given when the tangent of the talus surface tilted medially relative to the horizontal grid line [Fig. 2(D)].

To determine intra- and interobserver reliabilities of radiographic assessment, two orthopedic surgeons performed all radiographic assessments in 30 randomly selected knees twice, with a 3-week interval between evaluations. The intra- and interobserver reliabilities of measurements for the four radiographic measures were evaluated using intraclass correlation coefficients (ICCs). All ICCs of intra- and interobserver reliabilities of alignment measurements were satisfactory, >0.89 (range, 0.89–0.99); thus measurements taken by one investigator were used in the analyses.

Evaluations of clinical scores 1-year after HTO

Patients in the HTO group were evaluated 1-year after HTO at the outpatient department of our hospital by a single independent investigator using the pain and function subscales of the WOMAC[13] and the physical component (PCS) and mental component (MCS) subscales of the SF-36[14]. Because the WOMAC pain and function subscales are scored best-to-worst and have different maximum scores (20 points and 68 points, respectively) they were transformed to a 0–100 worst-to-best scale using the formula as follows: transformed score = 100 − (actual raw score × 100/maximum score).

Statistical analysis

All statistical analyses were performed using SPSS for Windows (Version 17.0; SPSS, Chicago, IL, USA), and P values < 0.05 were considered significant.

Values of the four radiographic measures were compared before and after HTO using the paired t-test. Additionally, the postoperative change in TPI was compared to that in the KJLO relative to the ground, and the postoperative changes in the knee and ankle joint line orientations relative to the ground were compared using paired t-tests.

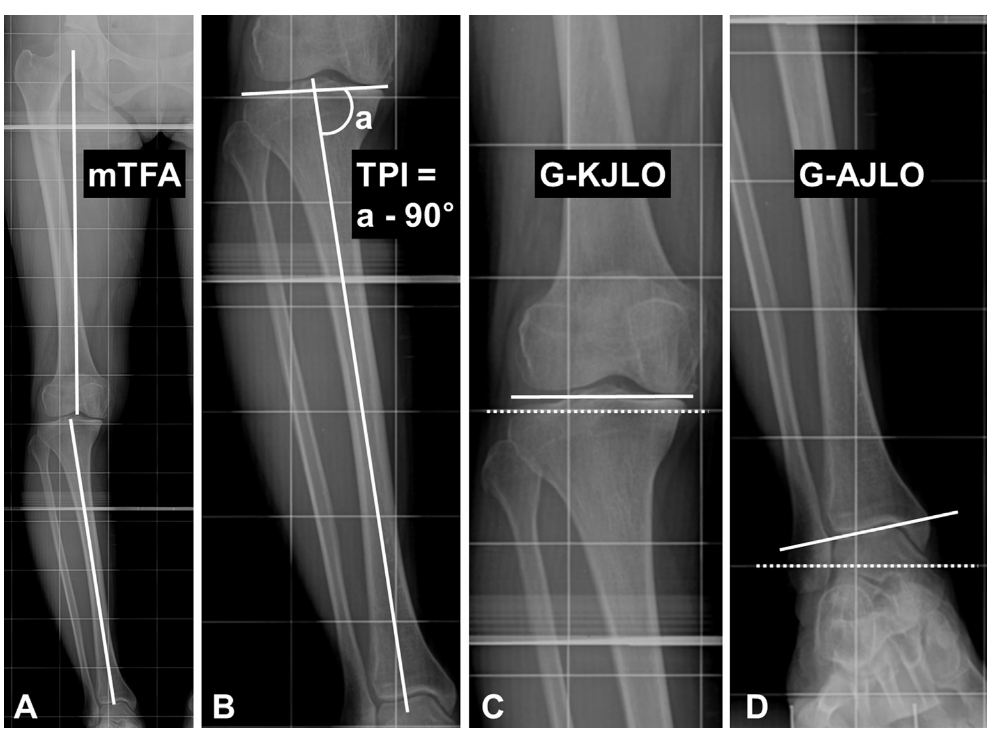

Fig. 2. Radiographic measurements. (A) the mechanical TF angle (mTFA), solid lines; (B) the tibial plateau inclination (TPI); (C) the KJLO relative to the ground (G-KJLO), solid line; and (D) the ankle joint line orientation relative to the ground (G-AJLO), solid line. Dotted line indicates the orientation of the ground. Detailed information on the measurements is described in the text.

Values of the four radiographic measures were compared between the control group and the HTO group (before and after HTO) using the independent *t*-test.

Associations between the value of the four radiographic measures after HTO and WOMAC subscales and SF-36 scores 1-year after HTO were evaluated using multiple linear regression analyses with the enter method, where the following potential confounders were included: gender, age, and BMI. The results of the regression analysis are presented as estimates (score/°, regression coefficients) and *P* values.

Results

Compared to pre-HTO condition, the values of the four radiographic measures significantly changed after HTO. Notably, after HTO the KJLO relative to the ground increased significantly less than did the TPI, due to a compensatory change of the ankle joint line orientation relative to the ground (Table I, Fig. 3). After HTO, the mean increases in mechanical TF angle and the TPI were 10.8° and 9.0°, respectively, whereas that of the KJLO was only 4.1°. We found that the decrease of the ankle joint line orientation relative to the ground (−6.8° on average) contributed to the relative small change of the KJLO; the sum of changes in those two orientations approximated the overall change of the mechanical TF angle after HTO.

After HTO, the KJLO relative to the ground was significantly different from that of the control group (4.9° on average difference, $P < 0.001$, Table II), despite the aforementioned dilution of the change in the KJLO after HTO by the decrease in ankle joint line orientation. Preoperatively, the KJLO relative to the ground of the HTO group differed to a lesser extent (0.8° on average difference, $P = 0.059$) from that of the normal controls; both the KJLOs were almost parallel to the ground. In addition, the pre- and postoperative values of the ankle joint line orientations of the HTO group differed significantly from those of the normal control with the opposite orientations (means differences, 4.4° and −2.4°, $P < 0.001$ and $P = 0.001$, respectively).

Based on multiple regression analyses, the values of the postoperative radiographic measures were not associated with postoperative 1-year WOMAC/SF-36 outcome scales in the HTO group (Table III).

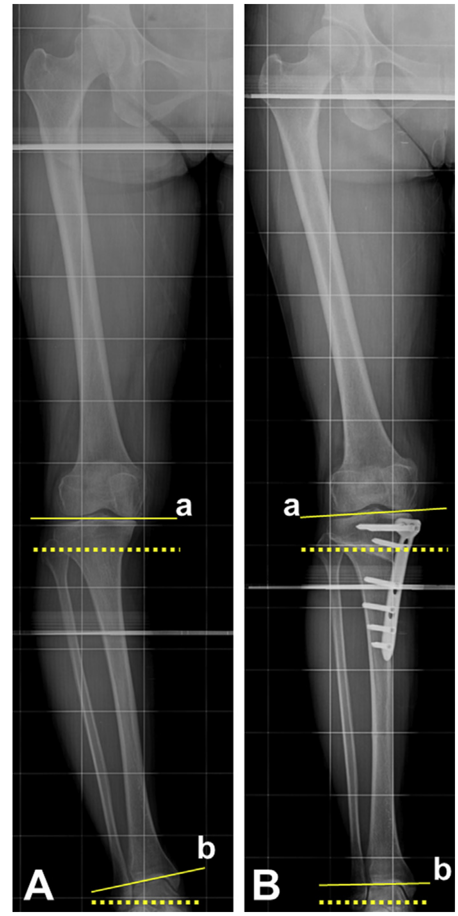

Fig. 3. Radiographs showing typical changes of the knee and the ankle joint line orientations relative to the ground. This 53-year-old female patient underwent HTO due to symptomatic varus OA in her right knee. After HTO, the mechanical TF angle increased 11.5° (from varus 8° to valgus 3.5°) and the TPI increased 10° (from −6.5° to 3.5°). (A) On the preoperative standing full-limb X-ray, the KJLO (line a) was 0.4° relative to the ground (dotted line) and the ankle joint line orientation (line b) was 12° relative to the ground. (B) On the postoperative standing full-limb X-ray, the KJLO (line a) became 3.6° (increased 3.2°) relative to the ground while the ankle joint line orientation (line b) became 1°(decreased 11°) relative to the ground.

Discussion

HTO is a frequent surgery for relatively younger patients with symptomatic varus knee OA[1–3,10]. However, because this procedure directly changes the geometry of only the proximal tibia (a slight overcorrection, 2–6°valgus mechanical alignment is the aim of limb alignment)[10], abnormal KJLO can frequently result, a concern that could limit correction angle or use of HTO by knee surgeons[7–9]. However, little evidence is currently available about whether abnormal KJLO adversely affects clinical outcomes after HTO[7]. Moreover, theoretically osteotomy of the tibia would influence the orientation of both the knee and ankle joints. Consequently, the change in the KJLO relative to the ground may be smaller because of a compensatory change in the ankle joint line orientation relative to the ground. To address these issues, we assessed the changes in the TPI, the knee- and the ankle joint line orientations relative to the ground after HTO and compared these measures in the HTO patients with those of the normal controls. Then, we investigated associations of these radiographic measures after HTO with clinical outcome scores 1-year after HTO.

Some limitations should be noted in the interpretation of our study findings. First, because of potential ethnic differences in anatomical characteristics, the findings may be different from that of Western populations. However, major values of our study are almost identical with those of a recent Western study[12]. Moreover, such differences in anatomical characteristics would minimally influence the postoperative changes that we observed. Second, the radiographic protocol, particularly the distance between both feet, could influence the knee and ankle joint line orientations relative to

Table I
Comparison of the four radiographic measures before and after HTO

Parameter	Pre-HTO	Post-HTO	Difference	*P* value
MTFA (°)	−8.3 ± 2.3	2.5 ± 2.2	10.8 ± 3.1	<0.001
TPI (°)	−5.6 ± 2.1	3.4 ± 3.0	9.0 ± 2.8*	<0.001
G-KJLO (°)	0.3 ± 2.1	4.4 ± 2.6	4.1 ± 2.1*,†	<0.001
G-AJLO (°)	8.8 ± 3.2	2.0 ± 3.9	6.8 ± 2.7†	<0.001

Data are presented as mean ± standard deviation.
Abbreviations: MTFA, mechanical TF angle; TPI, tibial plateau inclination; G-KJLO, knee joint line orientation relative to the ground; G-AJLO, ankle joint line orientation relative to the ground.
* After HTO the TPI increased significantly more than did the G-KJLO (paired *t*-test, $P < 0.001$).
† After HTO the G-AJLO increased significantly more than did the G-KJLO (paired *t*-test, $P < 0.001$).

Table II
Differences in the four radiographic measures between the normal control group and the HTO group (before HTO and after HTO)

Parameter	Normal control (mean ± SD)	Difference with normal control*			
		Pre-HTO	P value	Post-HTO	P value
MTFA (°)	−1.9 ± 2.4	−6.4 (−7.2, −5.5)	<0.001	4.4 (3.5, 5.2)	<0.001
TPI (°)	−3.6 ± 2.3	−2.0 (−2.8, −1.2)	<0.001	7.0 (6.0, 7.9)	<0.001
G-KJLO (°)	−0.5 ± 2.5	0.8 (−0.03, 1.7)	0.059	4.9 (4.0, 5.8)	<0.001
G-AJLO (°)	4.4 ± 3.9	4.4 (3.1, 5.7)	<0.001	−2.4 (−3.8, −1.1)	0.001

Abbreviations: SD, standard deviation; MTFA, mechanical TF angle; TPI, tibial plateau inclination; G-KJLO, knee joint line orientation relative to the ground; G-AJLO, ankle joint line orientation relative to the ground.
* Data are presented as mean and (95% confidence interval).

the ground[15]. However, potential variation in these radiographic measures was minimized by the aforementioned radiographic protocol in our center; we were able to obtain optimal radiographs for this study with patellar facing forward and an identical distance between both feet in all study subjects. Third, although we used multiple, validated outcome scales for evaluation of postoperative condition in knee OA patients, those scales may not be sensitive enough to detect subtle changes in higher functional activities[16]. In addition, we only evaluated 1-year postoperative outcomes, so we were not able to draw conclusions about on longer-term relationships. These issues should be addressed by future studies. Finally, sagittal alignment of the tibia, namely tibial slope, also can change after HTO, but we did not examine the relationship between the amount of tibial slope change and clinical outcomes in this study. Several studies revealed that tibial slope slightly increases after open-wedge HTO and slightly decreases after closing-wedge HTO[17,18]. However, despite of the opposite directions of tibial slope change between the two techniques, currently available comparative studies indicate that in terms of clinical outcomes, there is no significant difference between the two techniques[19,20]. Thus, we assumed that tibial slope change may not significantly influence on clinical outcomes after HTO. Moreover, as all the patients in our HTO group underwent open-wedge HTO, its influence on clinical outcomes may be even smaller than that in the aforementioned studies. Nevertheless, more detailed clinical significance of the slope changes should also be revealed by further studies.

A novel finding in this study is that after HTO size of the change of the KJLO relative to the ground was less than half that of the TPI that reflects the correction amount of the HTO. This finding appears to derive from compensatory changes in the ankle joint line orientation relative to the ground, which changed significantly more than the KJLO. We reasoned that the proximal tibial osteotomy would change the relative ankle joint line orientation more than the KJLO because of the longer lever arm. Thus, if the KJLO relative to the ground influences knee kinematics more than the TPI, which is an anatomical value within the tibia[7,12,21], knee kinematics might be less altered by HTO than expected. However, little evidence is currently available regarding the effect of the relative KJLO on knee kinematics[7], thus further studies are required. We also found that the postoperative change in the TPI, i.e., the amount of correction by osteotomy, was about 2° less than the change of the mechanical TF angle. The explanation for this finding could be that realignment by HTO resolves abnormal lateral joint space opening (varus angulation of the knee joint space and possibly ankle joint space) that was caused by increased adduction moment coupled with slack lateral ligament restraint in patients with preoperative varus malalignment[22]. In fact, the sum of the postoperative changes in the relative knee and ankle joint line orientation, which includes joint space changes after HTO, approximated the change of the mechanical TF angle.

However, the relative KJLO after HTO still indicated significantly more lateral tilt (about 5° on average) than that of normal knees, despite the compensatory change of the relative ankle joint line orientation. The two major reasons for this finding could be (1) relative KJLO of patients before HTO was similar to that of the normal controls and (2) the overcorrection nature of HTO. This study found that the average KJLOs of patients before HTO and the normal controls were almost parallel to the ground (0.3° vs −0.5°, respectively) and their difference was only 0.8° ($P = 0.059$). Consequently, the average KJLOs in patients after HTO became significantly different from that in the normal controls. In addition, because after HTO patients had about 4°more valgus alignment than the normal controls, the overcorrection produced most of this difference.

Regarding the relative KJLO, similar findings were observed in a recent study[12]. Victor *et al.* compared the tibial joint line angle relative to the floor in subjects with neutral alignment and with constitutional varus, and found that even though their mechanical alignments differed by 4°on average (varus 0.5° in the neutral group vs varus 4.5° in the varus group), the average tibial joint line angles relative to the floor in both groups were almost identical and parallel to the floor. Furthermore, the authors found that in arthritic knees with varus alignment this parallel orientation was not maintained (1.9° lateral tilt on average), which appears contradictory to our findings before HTO. However, the previous authors' arthritic knee group included a number of patients with more severe knee OA warranting TKA who had more severe varus malalignment than our patients group. Additionally, our definition of the KJLO (the line connecting the mid-points of medial and lateral knee joint space) differed from these and authors' definition of the tibial joint line (the tangent to the medial and lateral tibial plateau) can lead to a slight angle difference. Considering these factors, our findings nearly agree with the previous study.

The relative ankle joint line orientation in the patients before HTO was tilted significantly more laterally than in the normal controls. This novel finding suggests that the biomechanical

Table III
Associations between radiographic measures and WOMAC and SF-36 scores 1 year after HTO

Parameter	WOMAC pain*		WOMAC function*		SF-36 PCS		SF-36 MCS	
	Estimates (score/°)	P value	Estimates (score/°)	P value	Estimates (score/°)	P value	Estimates (score/°)	P value
Postoperative MTFA	0.12	0.455	0.03	0.876	−0.12	0.166	0.19	0.279
Postoperative TPI	−0.12	0.473	−0.18	0.284	−0.26	0.102	−0.01	0.949
Postoperative G-KJLO	−0.08	0.640	0.07	0.676	−0.02	0.893	0.02	0.915
Postoperative G-AJLO	−0.29	0.062	−0.13	0.433	0.12	0.438	−0.03	0.879

Multiple regression analyses were performed while controlling for these potential confounders, gender, age, and BMI.
Abbreviations: WOMAC, Western Ontario and McMaster Universities OA Index; SF-36, Short Form-36; PCS, physical component summary; MCS, mental component summary; MTFA, mechanical TF angle; TPI, tibial plateau inclination; G-KJLO, knee joint line orientation relative to the ground; G-AJLO, ankle joint line orientation relative to the ground.
* The original WOMAC scores were transformed to 0–100, worst-to-best scales.

remodeling process that maintained the KJLO parallel to the ground did not happen in the relative ankle joint line orientation[12,23]. After HTO, the relative ankle joint line orientation became more parallel to the ground (8.8° before HTO vs 2.0° after HTO), even though the ankle joint line orientation after HTO was slightly overcorrected compared to the normal controls probably due to intentional overcorrection strategy in HTO. This phenomenon may improve biomechanics of the ankle joint by permitting more even distribution of the weight on the ankle joint[24]. This finding may merit consideration in the treatment of patients with specific ankle diseases, such as intractable osteochondritis dissecans of the medial talar dome, combined with significant varus limb malalignment. Our study design and study subjects were not intended to determine the clinical significance of the ankle joint change; therefore, this issue needs to be addressed further.

We did not find any statistically significant associations between the postoperative radiographic measures evaluated in this study and the 1-year postoperative clinical outcomes of the patients who underwent HTO. This finding suggests that even though the radiographic measures were different from the normal condition, particularly those of the TPI and the KJLO relative to the ground, they would not adversely affect clinical outcomes 1-year after HTO. However, this finding does not assure that the deviations in the radiographic measures after HTO will have no adverse effects; because we did not evaluate long term outcomes, we were not able to determine whether such abnormal radiographic measures would adversely affect long term functional outcomes and survival of HTO. Moreover, our patients who underwent HTO were selected, the major component of their varus limb alignment was the proximal tibia (significant proximal tibia vara); thus, our findings should not be generalized to patients whose varus limb alignment originates from another source such as the distal femur.[7–9]

In conclusion, our study revealed that after HTO the relative KJLO changed significantly less than did the anatomical geometry of the proximal tibia because of simultaneous compensatory changes of the relative ankle joint line orientation. Nevertheless, we found that the relative KJLO after the HTO was significantly different from that of normal knees. However, we did not **find** that the postoperative values of the relative KJLO and other radiographic measures adversely affected clinical outcome scores 1 year after HTO in our study cohort. We believe that our findings warrant consideration in pre-and postoperative evaluations of patients undergoing HTO and further studies should evaluate prospectively the biomechanical implications of each parameter assessed in this study.

Author contributions

The following authors have made substantial contributions to the following: (1) the conception and design of the study (KML, CBC, MSP, TKK), acquisition of data (CYC, SBK), analysis and interpretation of data (KML, CBC, MSP), (2) drafting the article (KML, CBC), revising critical for important intellectual content (CYC, SBK, TKK), (3) final approval of the version to be submitted (KML, CBC, CYC, MSP, SBK, TKK).

Conflict of interest

The authors certify that we have no commercial associations that might pose a conflict of interest in connection with this article.

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Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.joca.2014.11.001.

References

1. W-Dahl A, Robertsson O, Lohmander LS. High tibial osteotomy in Sweden, 1998–2007: a population-based study of the use and rate of revision to knee arthroplasty. Acta Orthop 2012;83: 244–8.
2. Akizuki S, Shibakawa A, Takizawa T, Yamazaki I, Horiuchi H. The long-term outcome of high tibial osteotomy: a ten- to 20-year follow-up. J Bone Jt Surg Br 2008;90:592–6.
3. Saragaglia D, Blaysat M, Inman D, Mercier N. Outcome of opening wedge high tibial osteotomy augmented with a Biosorb(R) wedge and fixed with a plate and screws in 124 patients with a mean of ten years follow-up. Int Orthop 2011;35: 1151–6.
4. Chang CB, Koh IJ, Seo ES, Kang YG, Seong SC, Kim TK. The radiographic predictors of symptom severity in advanced knee osteoarthritis with varus deformity. Knee 2011;18:456–60.
5. Sharma L, Chmiel JS, Almagor O, Felson D, Guermazi A, Roemer F, *et al*. The role of varus and valgus alignment in the initial development of knee cartilage damage by MRI: the MOST study. Ann Rheum Dis 2013;72:235–40.
6. Sharma L, Song J, Dunlop D, Felson D, Lewis CE, Segal N, *et al*. Varus and valgus alignment and incident and progressive knee osteoarthritis. Ann Rheum Dis 2010;69:1940–5.
7. Amis AA. Biomechanics of high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2013;21:197–205.
8. Saragaglia D, Nemer C, Colle PE. Computer-assisted double level osteotomy for severe genu varum. Sports Med Arthrosc 2008;16:91–6.
9. Babis GC, An KN, Chao EY, Rand JA, Sim FH. Double level osteotomy of the knee: a method to retain joint-line obliquity. Clinical results. J Bone Jt Surg Am 2002;84-A:1380–8.
10. Hernigou P, Medevielle D, Debeyre J, Goutallier D. Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. J Bone Jt Surg Am 1987;69: 332–54.
11. Chang CB, Choi JY, Koh IJ, Seo ES, Seong SC, Kim TK. What should be considered in using standard knee radiographs to estimate mechanical alignment of the knee? Osteoarthritis Cartilage 2010;18:530–8.
12. Victor JM, Bassens D, Bellemans J, Gursu S, Dhollander AA, Verdonk PC. Constitutional varus does not affect joint line orientation in the coronal plane. Clin Orthop Relat Res 2014;472:98–104.
13. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol 1988;15:1833–40.
14. Ware Jr JE, Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Med Care 1992;30:473–83.
15. Moreland JR, Bassett LW, Hanker GJ. Radiographic analysis of the axial alignment of the lower extremity. J Bone Jt Surg Am 1987;69:745–9.
16. Na SE, Ha CW, Lee CH. A new high-flexion knee scoring system to eliminate the ceiling effect. Clin Orthop Relat Res 2012;470: 584–93.
17. Ducat A, Sariali E, Lebel B, Mertl P, Hernigou P, Flecher X, *et al*. Posterior tibial slope changes after opening- and closing-

wedge high tibial osteotomy: a comparative prospective multicenter study. Orthop Traumatol Surg Res 2012;98: 68–74.
18. El-Azab H, Glabgly P, Paul J, Imhoff AB, Hinterwimmer S. Patellar height and posterior tibial slope after open- and closed-wedge high tibial osteotomy: a radiological study on 100 patients. Am J Sports Med 2010;38:323–9.
19. Song EK, Seon JK, Park SJ, Jeong MS. The complications of high tibial osteotomy: closing- versus opening-wedge methods. J Bone Jt Surg Br 2010;92:1245–52.
20. Amendola A, Bonasia DE. Results of high tibial osteotomy: review of the literature. Int Orthop 2010;34:155–60.
21. Howell SM, Howell SJ, Kuznik KT, Cohen J, Hull ML. Does a kinematically aligned total knee arthroplasty restore function without failure regardless of alignment category? Clin Orthop Relat Res 2013;471:1000–7.
22. Dugdale TW, Noyes FR, Styer D. Preoperative planning for high tibial osteotomy. The effect of lateral tibiofemoral separation and tibiofemoral length. Clin Orthop Relat Res 1992:248–64.
23. Bellemans J, Colyn W, Vandenneucker H, Victor J. The Chitranjan Ranawat award: is neutral mechanical alignment normal for all patients? The concept of constitutional varus. Clin Orthop Relat Res 2012;470:45–53.
24. Stufkens SA, van Bergen CJ, Blankevoort L, van Dijk CN, Hintermann B, Knupp M. The role of the fibula in varus and valgus deformity of the tibia: a biomechanical study. J Bone Jt Surg Br 2011;93:1232–9.