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Original Article

Association between clinical symptoms and lateral thrust 12 months after high tibial osteotomy

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Abstract. [Purpose] This study aimed to assess the correlation between lateral thrust and clinical symptoms after high tibial osteotomy and determine lower limb alignments that may decrease lateral thrust. [Participants and Methods] We included 54 patients (73 knees) who underwent high tibial osteotomy. Clinical symptoms, including the Japanese Orthopaedic Association score and the hip–knee–ankle angle measured via radiography, were assessed 12 months postoperatively. Lateral thrust was measured using three-dimensional motion analyses. Logistic regression was used to calculate the cut-off values with good Japanese Orthopaedic Association score and lateral thrust as dependent variables and both lateral thrust and hip–knee–ankle angle as independent variables. [Results] The lateral thrust cut-off was 3.1° (sensitivity: 0.83; specificity: 0.74; area under the curve: 0.76), while that of the hip–knee–ankle angle was 1.9° of valgus (sensitivity: 0.71; specificity: 0.81; area under the curve: 0.72). [Conclusion] Good clinical outcomes after high tibial osteotomy can be expected with a lateral thrust of ≤3.0°, indicating that the target hip–knee–ankle angle should be 2.0° valgus. In cases where valgus alignment is insufficient, lateral thrust may develop, which should be assessed using gait analysis.

Key words: Alignment, Gait, High tibial osteotomy

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INTRODUCTION

High tibial osteotomy (HTO) for knee osteoarthritis (KOA) is conducted to correct the bowing tibia and disperse the load to the medial side of the knee joint. The target postoperative valgus knee alignment is 2°–4° at the hip–knee–ankle (HKA) angle[1)], and good surgical results have been reported. Postoperative clinical symptoms decreased after valgus alignment in radiological outcomes[1)]. Furthermore, gait stability reduces the medial knee joint compartment[2)]. Therefore, gait analysis is as essential as radiographic assessment.

Lateral thrust (LT) refers to an abnormal knee joint motion in the early stance phase where the knee joint center moves laterally[3)]. Increased LT indicates increased load on the medial knee joint; this increase is associated with 4.3 times increased risk of KOA progression and increased medial knee pain[3, 4)]. LT is defined as an increase in the number of changes in the

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knee joint varus angle determined through gait analyses using a three-dimensional motion analyzer[4]. Increased knee varus alignment and the associated increase in the knee adduction moment (KAM)[5] during gait are reported as the causes of LT. In many cases, LT is reduced owing to a variation in the valgus alignment by HTO[6, 7].

However, it has been shown that postoperative LT persisted in 30% of all patients after HTO[8]. In addition, the association between postoperative LT and clinical symptoms has not been entirely evaluated. Naudie et al.[9] reported that preoperative LT was associated with clinical symptoms after HTO. We hypothesized that residual LT, which indicates knee joint loading, could be linked to postoperative clinical symptoms. This study aimed to determine the association between clinical symptoms after HTO and postoperative LT and to identify the cut-off values for postoperative valgus knee alignment that results in the complete absence of LT.

PARTICIPANTS AND METHODS

This was a cross-sectional study conducted 12 months after HTO. We included 320 patients who underwent HTO for KOA with Kellgren & Lawrence classification grade I or higher at our hospital between 2017 and 2021. Patients who did not provide their informed consent to participate in the study; those with a history of surgery on lower limbs (the measuring limb), a musculoskeletal or neurological disease that inhibited them from walking alone for >10 m, or a ligament injury and joint instability; and highly obese patients with a body mass index (BMI) of >35 (Fig. 1) were excluded[6, 8, 10–12]. The surgery type was selected according to a previous study[12]; the choice was between medial opening wedge HTO (MOWHTO) and hybrid closed wedge HTO (HCWHTO). MOWHTO was employed if all of the following additional criteria were met: a preoperatively calculated opening wedge gap of <15 mm, smoking <20 cigarettes per day, weight <80 kg, no severe osteoporosis, well-controlled blood sugar levels if diabetic, and a knee without post-traumatic skin scarring[12]. All the study protocols were approved by the Ethics Review Board of Kinjo University (approval numbers: 29-4) and Yawata Medical Center (approval numbers: 29-6) and conformed to the Declaration of Helsinki.

During gait analysis, the patients were asked to walk comfortably five times barefoot on a 10-m walkway. When the participant stepped on the ground reaction force plate in the 4–6-m section one foot at a time, the measurement was deemed successful; when the participant stepped off, the measurement was taken again. A three-dimensional motion analyzer (VICON MX, Oxford Metrics, Oxford, UK) and three force plates (BP400600HF-2000, AMTI, Watertown, MA, USA) were used for the measurements. Nine infrared cameras (100 Hz), three ground reaction force plates (1,000 Hz), and the 3D spatial coordinates of each marker were recorded on a personal computer. Reflective markers, each with a diameter of 14 mm, were affixed to 35 anatomical markers on the entire body according to the Plug-in-Gait full-body model[13]. In the stance phase of the gait cycle, the time point when the ground reaction force was ≥20 N was characterized as the "initial contact", and the subsequent time when the floor reaction force was <20 N was characterized as the "toe-off"[7]. The time of ground contact of the measured lower limb was normalized to initial contact (0%) and toe-off (100%); further, the maximum change in the knee joint varus and flexion angle and the knee joint adduction moment 0%–50% of the first half of the time were extracted[3]. The kinematic data included knee joint flexion, varus angles, and the amount of change in these phases. KAM, a kinematic data, was maximum at the initial ground interval and was normalized by height and weight (%BW*Ht)[2]. LT was defined

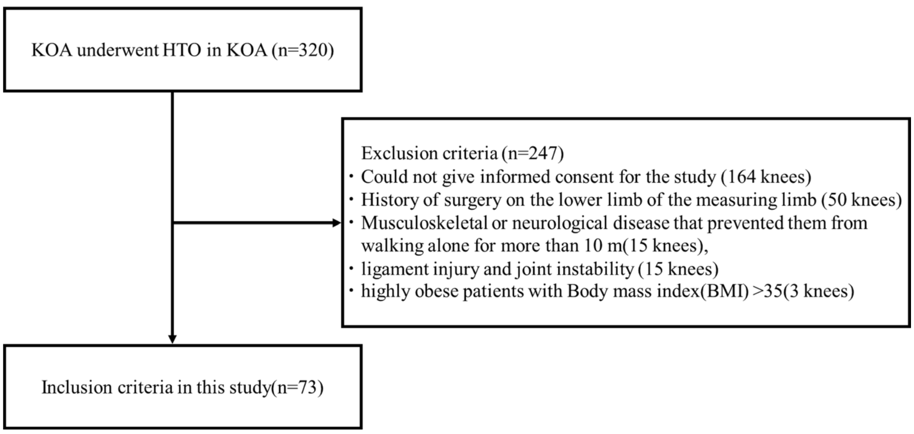

Fig. 1. Flowchart for selection of research participants.
We included 320 patients who underwent HTO for KOA with Kellgren & Lawrence classification grade I or higher at our hospital between 2017 and 2021. Patients who did not provide their informed consent to participate in the study; those with a history of surgery on lower limbs (the measuring limb), a musculoskeletal or neurological disease that inhibited them from walking alone for >10 m, or a ligament injury and joint instability; and highly obese patients with a body mass index (BMI) of >35 were excluded.
HTO: high tibial osteotomy; KOA: knee osteoarthritis.

as the difference between the maximum and minimum change in the knee varus angle during the early stance phase[4, 7]. The angular velocity of the knee joint varus angle was the time derivative of the change in the knee joint varus angles every 0.01 s in the software. The average of five measurements was used for LT, KAM, and kinematic data. X-ray was taken while standing on both legs, and the HKA angle was measured (positive values indicate varus; negative values, valgus). The total Japanese Orthopaedic Association (JOA) score was used to evaluate clinical symptoms for osteoarthritic knees[14]. The JOA score is an observational knee scoring system for assessing symptoms, knee pain, physical impairment, and disability[14]. This evaluation battery is considered to exhibit good clinical performance for high scores. These kinematic and kinetic data were obtained 12 months postoperatively. JOA scoring and radiographic measurement were performed preoperatively and 12 months postoperatively.

The lower quartile of the JOA score at postoperative 12 months for the total population was deemed <85 for the poor group and ≥85 points for the good group; differences in LT between the two groups were examined using Student's t-test. Next, the cut-off value of LT was determined using logistic regression analyses, receiver operating characteristics (ROC curves), and the area under the curve (AUC), with the JOA score as the dependent variable and LT as the independent variable. Next, those who surpassed the LT cut-off value were assigned to the LT group, whereas those who were below the cut-off value were assigned to the non-LT group.

The differences between the two groups were analyzed using Student's t-test and the χ^2 test for differences in basic data and kinematic data and KAM. Finally, a logistic regression analysis, with the LT as the dependent variable and HKA as the independent variable, ROC curve, and AUC were used to determine the cut-off value of the HKA. These were found to be significant at the 5% level. All statistical analyses were conducted using EZR version 1.52 (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R version 4.02 (The R Foundation for Statistical Computing, Vienna, Austria). More specifically, it is a modified version of R commander designed to add statistical functions frequently applied in biostatistics[15].

RESULTS

In this study, we included 54 patients with 73 knees (Fig. 1) after excluding patients who could not provide their informed consent to participate in the study (164 knees), patients with a history of surgery on the lower limb/the measuring limb (50 knees), those with a musculoskeletal or a neurological disease that prevented them from walking for >10 m (15 knees), those with a ligament injury and joint instability (15 knees), and highly obese patients with a BMI of >35 (3 knees) (Fig. 1). The mean LT was 3.3° ± 5.0° in the poor JOA group and −1.4° ± 7.7° in the good JOA group (p<0.01) (Table 1). Figure 2 depicts that logistic regression analysis with JOA as the dependent variable revealed a cut-off value for LT of 3.1° (sensitivity: 0.83; specificity: 0.74; AUC: 0.76). Table 2 presents a comparison of the values in the LT and non-LT groups using the Student's t-test and the χ^2 tests, which discovered significant differences in the basic information for the post-HKA. The outcomes of the gait analysis revealed higher values in the LT group for the max knee varus angle, knee varus angle velocity, and KAM. The outcomes of the logistic regression analysis with the LT as the dependent variable and the HKA as the independent variable are depicted in Table 2. As presented in Table 3, the logistic regression analysis revealed a significant positive correlation with HKA, with a cut-off value of −1.90° (sensitivity: 0.69; specificity: 0.83; AUC 0.71) (Fig. 3).

Table 1. Patient characteristics and gait analysis results for groups divided by good and poor JOA

	Poor JOA group (n=23)	Good JOA group (n=50)
Age (years)	63.9 ± 7.2	62.8 ± 6.4
Gender (male/female)	12/11	27/23
BMI (kg/m²)	24.8 ± 2.1	25.1 ± 2.8
Operative type (OWHTO/HCWHTO)	12/11	35/15
KL grade (I, II, III, IV)	1/3/11/8	8/12/24/6
Pre HKA (°)	5.4 ± 3.3	5.2 ± 3.0
Post HKA (°)	−1.1 ± 4.0	−2.0 ± 3.5
Pre JOA (points)	78.3 ± 6.5	76.0 ± 8.2
Post JOA (points)	75.9 ± 5.8	92.7 ± 5.0**
Post LT	4.1 ± 3.0	2.2 ± 2.5**

Mean ± standard deviation, **p<0.01.
JOA: Japanese Orthopaedic Association score; BMI: body mass index; LT: lateral thrust; OWHTO: opening wedge high tibial osteotomy; KL grade: Kellgrence & Lawrence grade; HCWHTO; Hybrid closed wedge high tibial osteotomy; HKA: hip–knee–ankle angle.

DISCUSSION

There are two main outcomes of this study. First, there was a significant association between the JOA score and LT, indicating that the group with a poor JOA score had LT. Second, an HKA of −1.9° (knee joint valgus 1.9°) was demonstrated to be the cut-off value at which LT did not appear.

In a previous study on the association between clinical symptoms and LT, Naudie et al. revealed that patients who underwent arthroplasty after 10 years of HTO had preoperative LT as a feature[6]. In this study, the association between postoperative clinical symptoms and LT was explored, and it was discovered that the poor postoperative JOA score group had LT; the cut-off value of LT for the JOA score was 3.1°. Fukaya et al.[16] and Sosdian et al.[17] revealed that in severe KOA with LT, three-dimensional gait analyses demonstrated LT values of 3.1° ± 2.1° and 3.2° ± 1.5°, which estimated the outcomes of the current study. The reason for the link between the JOA score and postoperative LT after HTO is deduced from previous research on KOA[3, 18], where increased LT caused increased loading on the medial knee joint and the knee cartilage.

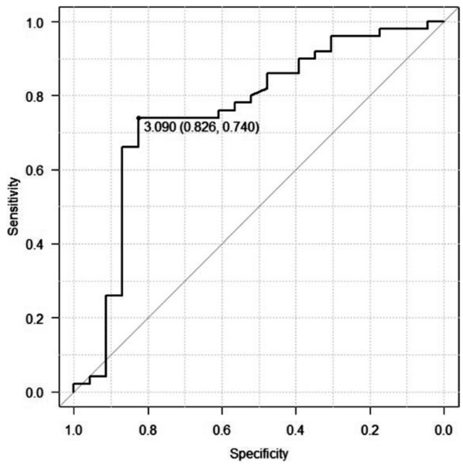

Fig. 2. Cut-off values for LT with low impact on JOA score failure. Logistic regression analysis with JOA as the dependent variable showed a cut-off value for LT of 3.1° (sensitivity: 0.83; specificity: 0.74; AUC: 0.76). LT: lateral thrust: JOA: Japanese Orthopaedic Association.

Table 2. Patient characteristics and gait analysis results on groups divided by the presence or absence of LT

	nonLT group (n=41)	LT group (n=32)
Age (years)	63.6 ± 6.3	62.6 ± 7.1
Gender (male/female)	(15/26)	(19/13)
BMI (kg/m²)	25.6 ± 2.6	24.3 ± 2.3
Operative type (OWHTO/HCWHTO)	28/13	19/13
KL grade (I, II, III, IV)	4/13/18/5	4/2/17/8
HKA (°)	−2.8 ± 3.3	−0.3 ± 3.7*
Gait speed (°/s)	13.4 ± 1.5	12.9 ± 1.1
Knee flex angle in 0% stance phase (°)	7.8 ± 4.9	8.1 ± 4.2
Maximum value of the knee flex angle in 0–50% stance phase (°)	17.1 ± 7.1	18.2 ± 5.7
Amount of change in knee joint flexion angle during stance phase 0–50% (°)	9.3 ± 4.2	8.7 ± 6.4
Knee varus angle in 0% stance phase (°)	−2.3 ± 7.2	−2.1 ± 4.4
Maximum value of the knee varus angle in 0–50% stance phase (°)	−1.4 ± 7.7	3.3 ± 5.0**
Knee varus angle velosity (°/s)	26.9 ± 21.4	70.9 ± 23.8**
KAM (%*Ht)	2.0 ± 0.7	2.5 ± 0.9*

Mean ± standard deviation, *p<0.05, **p<0.01.
LT: lateral thrust; BMI: body mass index; HKA: the hip–knee–ankle angle; OWHTO: opening wedge high tibial osteotomy; KL grade: Kellgrence & Lawrence grade; HCWHTO: Hybrid closed wedge high tibial osteotomy; HKA: hip knee ankle; KAM: knee adduction moment.

Table 3. Results of logistic regression analysis of LT and HKA angles

Dependent variable: LT	Difference (95% confidence interval)			
	Unadjusted	Ajusted for age, gender and BMI	Ajusted for age, gender, BMI, and operative type	Ajusted for age, gender, BMI, operative type, and gait speed
HKA	1.23 (1.06, 1.43)**	1.20 (1.03, 1.41)*	1.20 (1.03, 1.41)*	1.24 (1.04, 1.47)*

*p<0.05, **p<0.01.
LT: lateral thrust; BMI: body mass index; HKA: hip–knee–ankle angle.

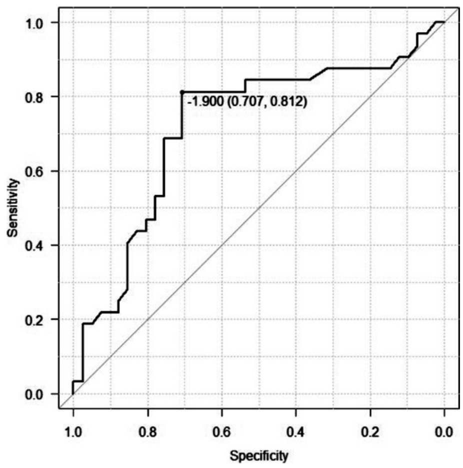

Fig. 3. Cut-off value of HKA angle at which LT does not appear.
The logistic regression analysis revealed a significant positive association with HKA, with a cut-off value of −1.90° (sensitivity: 0.69; specificity: 0.83; AUC 0.71).
HKA: hip–knee–ankle; LT: lateral thrust; AUC: area under the curve.

The cut-off value of the HKA at which LT did not appear was −1.90° (1.9° valgus). The cause of the HKA showing varus alignment after HTO may be the corrective loss linked to postoperative changes over time. As a target value for HKA after HTO, Schröter et al.[1] identified a target value of 2°–4° valgus after HTO. The mean HKA of the participants of this study was −0.3° ± 3.7° in the LT group compared with −2.8° ± 3.3° in the non-LT group. This indicates that a correction loss may have occurred in the LT group. Furthermore, the varus angle and KAM during gait were observed to be lower in the non-LT group (Knee varus angle: −1.4° ± 7.7° valgus and KAM: 2.0% ± 0.7% × Ht) than LT group (Knee varus angle: 3.3° ± 5.0° varus and KAM: 2.5% ± 0.9% × Ht). The outcomes revealed that the knee valgus angle during gait decreased in the LT group and KAM was higher in the LT group. This is believed to be due to an increase in the KAM as the distance between the center of the knee joint and the floor reaction force line linking the ground reaction force to the body's center of gravity during gait increased because of an increase in the knee varus alignment. According to these results, it can be inferred that KAM increased owing to the presence of knee varus alignment during gait when the HKA was insufficient, which was associated with LT development. The findings of this study indicated that LT ≤3.0° can produce a good clinical outcome after HTO and that the HKA should target 2.0° of valgus to accomplish this. The importance of assessing LT using gait analysis was suggested for cases in which intraoperative or postoperative hinge fractures resulted in the loss of correction of the knee valgus alignment. The study also suggested the need to improve gait during postoperative physiotherapy in order to prevent corrective loss over time.

This study had three limitations: first, patients who underwent MOWHTO and HCWHTO were included in the study population as there are few reports on the differences in gait parameters between the two techniques. In the present study, there was no difference in the percentage of procedures in the two groups divided by the presence or absence of LT and JOA. In the future, it is considered necessary to calculate the cut-off values at which LT does not appear for each procedure. Second, this was a cross-sectional study, which implies that the causal relationship between LT and HKA could not be identified. Further analyses of the association between LT and HKA should be investigated in a longitudinal study from the preoperative period to 12 months postoperatively. Finally, the study had a small sample size. Ideally, a multivariate analysis should use a sample size of a smaller number of events × 10 cases. In the multivariate analysis of the present study, five covariates were added step by step based on previous studies. Moreover, the LT group consisted of only 32 cases; hence, it is necessary to add an additional sample size.

Funding and Conflict of interest

All authors declare that they have no known competing financial interests or personal relationships that could influence the work reported in this paper.

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