



HOKKAIDO UNIVERSITY

Title	Higher Association of Pelvis-Knee-Ankle Angle Compared With Hip-Knee-Ankle Angle With Knee Adduction Moment and Patient-Reported Outcomes After High Tibial Osteotomy
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1 **Higher Association of Pelvis-Knee Ankle angle compared with Hip-Knee-Ankle Angle with Knee Adduction**
2 **Moment and Patient-Reported Outcomes after High Tibial Osteotomy**

3
4 **Abstract**

5 **Background:** High tibial osteotomy (HTO) reduces the load distribution of the medial compartment by modifying
6 leg alignment. Knee adduction moment (KAM), a surrogate measure of dynamic loading in the knee joint,
7 decreases after HTO. However, leg alignment does not fully account for KAM.

8 **Purpose:** To assess the association between pelvis-knee-ankle angle (PKA), a novel radiographic parameter
9 reflecting leg alignment and pelvic width, and KAM and patient-reported outcomes (PROMs) after HTO.

10 **Study design:** Cross sectional study

11 **Methods:** PKA is the angle between the line connecting the midpoint of the anterior superior iliac spine and the
12 center of the knee joint and the mechanical axis of the tibia. Further, 54 patients with medial compartment knee
13 osteoarthritis and varus alignment who underwent three-dimensional gait analysis preoperatively and 2 years after
14 medial open-wedge HTO were evaluated. The primary outcomes were hip-knee-ankle angle (HKA), PKA, KAM
15 peaks, and Knee Society Score (KSS). Single and multivariate regression analysis including PKA and KAM peaks
16 as well as other demographic and radiologic factors was performed.

17 **Results:** HKA was weakly correlated with the first peak KAM ($r=-0.33$, $p<0.01$) and second peak ($r=-0.27$,
18 $p=0.01$) before HTO, but not significantly correlated after HTO. PKA was moderately correlated with the first
19 peak KAM ($r=-0.45$, $p<0.01$) and second peak ($r=-0.45$, $p < 0.01$) before HTO and with the first peak KAM
20 ($r=-0.51$, $p < 0.01$) and second peak KAM ($r=-0.56$, $p<0.01$) after HTO. Multivariate linear regression revealed
21 that postoperative PKA was still associated with the KAM peaks after HTO. Only postoperative PKA was
22 correlated with the KSS satisfaction subscale ($r=-0.30$, $p=0.03$).

23 **Conclusion:** Although HKA was not correlated with KAM peaks after HTO, PKA was significantly correlated
24 with KAM peaks in patients with varus knee osteoarthritis after HTO.

25 **Clinical relevance:** PKA can be a potential radiographic parameter in HTO planning with consideration of
26 postoperative mediolateral load distribution.

27
28 **Key Terms:** high tibial osteotomy, knee, osteoarthritis, knee adduction moment, gait analysis

29 **What is known about the subject:** Leg alignment is associated with KAM. However, it does not fully account
30 for postoperative KAM after HTO.

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32 **What this study adds to existing knowledge:** The association between PKA, a novel radiographic parameter
33 reflecting pelvic width and leg alignment, and postoperative KAM and PROMs was higher than that between
34 PKA and leg alignment after HTO.

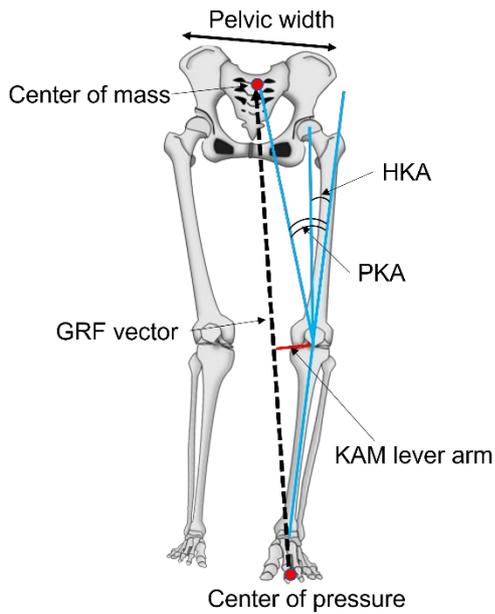
35 **Introduction**

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Malalignment is a biomechanical factor associated with abnormal stress on the knee joint, which leads to knee osteoarthritis (OA).¹¹ Knee adduction moment (KAM) is a representative measure of the load distribution of the knee joint.^{4, 25} That is because KAM is correlated with mediolateral load distributions^{17, 25} and KAM is an important factor of knee OA progression³⁰ and severity.³⁵ The association between leg alignment and KAM was higher than that between KAM and other factors such as toe-out gait^{3, 14, 17} and lateral body lean.^{14, 31} Thus, KAM was not completely accounted for leg alignment.^{14, 17}

Valgus high tibial osteotomy (HTO) is commonly used in the treatment of medial OA with varus alignment,^{2, 12, 18} because HTO reduces the load distribution in the medial compartment by modifying leg alignment and slowing disease progression. KAM decreases after HTO,^{7, 10, 33} and the change in leg alignment was associated with the change in KAM after HTO.^{7, 26} However, a recent meta-analysis showed that the amount of alignment correction and postoperative valgus alignment were not correlated with reduced KAM after HTO.²² A radiographic parameter highly correlated with KAM compared to leg alignment will be useful in HTO planning with consideration of mediolateral load distribution.

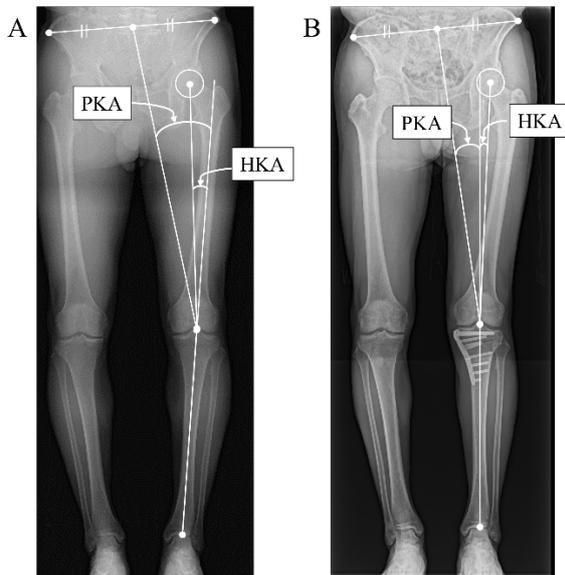
Moment is the product of the ground reaction force (GRF) and the moment lever arm. The GRF vector rises from the center of pressure toward the center of mass, which lies anterior to the second sacral vertebra in a one-leg standing position.³² Given the correlations between the GRF vector and KAM lever arm and conventional mechanical axis (hip–knee–ankle angle [HKA], Figure 1), we hypothesized that a radiographic parameter reflecting both leg alignment and pelvic width could have a higher correlation with KAM lever arm and KAM than HKA. Thus, in this study, we developed a pelvis–knee–ankle angle (PKA), a novel radiographic parameter used in full-length standing radiographs and defined as the angle between the line connecting the midpoint of the anterior superior iliac spine and the center of the knee joint with the mechanical axis of the tibia (Figure 2).



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60 **Figure 1.** Schema depicting the association among the GRF vector, KAM lever arm, pelvic width, and HKA and
 61 PKA in a one-foot standing position. GRF, ground reaction force; KAM, knee adduction moment; HKA, hip-
 62 knee-ankle angle.

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65 **Figure 2.** Radiographic parameters on a full-length standing radiograph. **A.** Valgus alignment. **B.** Varus alignment.
 66 Varus and valgus alignments were the negative and positive values of HKA, respectively. HKA, hip-knee-ankle
 67 angle; PKA, pelvis-knee-ankle angle; point S, defined as the midpoints of both the anterior superior iliac spines;
 68 line A, defined as the line connecting point S and the center of the knee joint; line B, defined as the line connecting
 69 the center of the knee joint and the ankle joint (referred to as the mechanical axis of the tibia); and PKA, defined
 70 as the smaller angle between lines A and B.

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A current study aimed to assess the association between PKA and KAM and clinical outcomes in patients with varus knee OA before and after HTO. We hypothesized that PKA has a higher correlation with KAM than HKA before and after HTO.

Materials and methods

Study design

This study was approved by the institutional review board of (##), and informed consent was obtained from each participant. We retrospectively recruited all patients who underwent open-wedge HTO and gait analysis before and after HTO at ## from 2013 to 2017. The indications of open-wedge HTO in our hospital were moderate varus leg alignment (HKA angle of $<-10^\circ$) and absence of moderate or severe OA in the patellofemoral joint and lateral compartment (Kellgren–Lawrence grade of <2).²¹ The exclusion criteria included patients who did not provide informed consent and those who could not undergo gait analysis without a gait aid. Of the 78 patients who underwent HTO, 54 were finally included in the analysis (Table 1) (flow chart in the Supplemental File).

Table 1. Baseline demographic and clinical characteristics (n = 54)^a

Characteristics	Values
Age, years	58.1 ± 6.1
Male/female sex, n	27/27
Height, cm	161.4 ± 8.1
Weight, kg	69.5 ± 9.2
BMI, kg/m ²	26.6 ± 2.8
HKA, degree	-4.0 ± 2.3
PKA, degree	15.1 ± 2.2
MPTA, degree	84.4 ± 2.0
Kellgren–Lawrence grade 1/2/3/4	5/14/33/2

^aData were expressed as mean ± standard deviation unless otherwise stated.

BMI, body weight index; HKA, hip–knee–ankle angle; PKA, pelvic–knee–ankle angle; MPTA, medial proximal tibial angle
Varus alignment was the negative value of HKA.

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Surgical procedure

All surgeries were performed by a senior orthopedic surgeon with 20 years of experience in performing knee surgery. The surgeon used the same operative technique, as described in a previous study,¹⁹ with the open-wedge HTO system and a locking plate (Tomofix [DePuy Synthes, West Chester, PA, USA] or the TriS Medial HTO plate system [Olympus Terumo Biomaterials, Tokyo, Japan]). As reported in a previous study, the Miniaci method²⁸ was used in preoperative planning.¹⁹ The intended angle of correction was calculated preoperatively to deliver a weight-bearing line of 62.5% of the tibial width, which is based on the magnitude of malalignment and status of the articular cartilage in the lateral tibiofemoral compartment.

Radiographic evaluation

The full-length standing anteroposterior radiograph images of the lower limb were taken with a long cassette while in the bipedal standing position, and they were used in the radiographic measurement. Each patient's foot position and digit direction on a radiolucent platform at the patella-neutral position were routinely recorded. Postoperative radiograph images were taken at the same foot position. To maintain the reproducibility of the radiographic evaluation, a bipedal standing radiograph was taken and foot position recording was performed. All radiographic images were digitally acquired using the picture archiving and communication system software (NEOVISTA I-PACS SX2, Konica Minolta Japan, Inc., Tokyo, Japan). Assessments were conducted using the software while controlling the magnification. The evaluation parameters were as follows: point S, defined as the midpoints of both the anterior superior iliac spines; line A, defined as the line connecting point S and the center of the knee joint; line B, defined as the line connecting the center of the knee joint and the ankle joint (referred to as the mechanical axis of the tibia); and PKA, defined as the smaller angle between lines A and B (Figure 2A). The varus and valgus alignments were the negative and positive values of HKA, respectively. HKA and PKA were measured before and 2 years after HTO.

Clinical evaluation

Clinical assessment was performed using the new Knee Society Score (KSS),³⁴ which was considered a patient-reported outcome measure (PROM) before and 2 years after HTO.

121 **Gait analysis**

122 As described in a previous study, three-dimensional gait analysis was performed before and 2 years after HTO.²⁹
123 Kinematic data were acquired using a three-dimensional motion capture system (RroRflex, Qualisys AB Inc.,
124 Gothenburg, Sweden) with eight infrared light cameras. Moreover, ground reaction forces during the tests were
125 measured using two multicomponent force plates (OR6, Advanced Mechanical Technology Inc., Watertown, New
126 York). Motion and force data were collected at 120 Hz. The three-dimensional knee kinematics were obtained
127 using the point cluster technique.^{5, 29} Reflective markers were placed on the lower limbs (56 markers) and the
128 acromion on both sides.²⁹ An overabundance of markers (a cluster) was placed on each segment to minimize skin
129 motion artifacts caused by segmental form change attributed to muscle contraction and marker oscillation.^{5, 29}
130 The participants walked barefoot at a self-selected comfortable speed along a 15-m walkway without assistive
131 devices and took a rest before each trial until they had recovered from fatigue. Three sets of data with a whole
132 gait cycle on the bilateral limbs were obtained. We collected the radiographic and gait data on the bilateral limbs
133 of each patient for analysis. External knee adduction moments were calculated using the kinematic and kinetic
134 data with a commercial software (Qualisys Track Manager 3D, Qualisys AB Inc., Gothenburg, Sweden) using a
135 bottom-up dynamic-linked segment model.²³ The average data from three trials were obtained and used for the
136 analysis of each limb.

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138 **Reliability of PKA measurement**

139 We assessed the reliability of HKA and PKA measurements on full-length standing anteroposterior radiographs
140 in the bipedal standing position in patients who underwent two sets of full-length standing anteroposterior
141 radiographs before and after unicompartmental knee arthroplasty (UKA) within 4 weeks. The inclusion criteria
142 for UKA were patients with an HKA of $<-5^\circ$, those with a flexion contracture of $<-10^\circ$, and those with a body
143 mass index of $<25 \text{ kg/m}^2$. Based on these criteria, there were minimal changes in the posture and leg alignment
144 of the contralateral side before and after UKA. In total, 100 randomized radiograph images of 50 patients before
145 and after UKA were assessed in two separate trials. Intrarater reliability, interrater reliability, and interradiograph
146 reliability (the mean of the first radiograph in trials 1 and 2 vs. the mean of the second radiograph in trials 1 and
147 2) were calculated.

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149 **Statistical analysis**

150 Statistical analysis was performed using JMP Pro version 14.0 (SAS Institute Inc.). A P value of <0.05 was

151 considered statistically significant. The paired *t*-test was used to compare variables before and after HTO. A simple
152 linear regression model was then used to evaluate the correlation between radiographic and background
153 characteristics and KAM before and after HTO. The association between postoperative PKA and the postoperative
154 first or second KAM peaks assessed via a multivariate regression analysis after adjusting for factors, including
155 age, sex, gait speed, and radiographic OA severity, was evaluated. HKA was not significantly correlated with the
156 postoperative first and second KAM peaks in the simple linear regression analysis. Hence, it was excluded from
157 the multivariate analysis.

158 Relative reliability was estimated using an intraclass correlation coefficient (ICC).²⁷ The ICCs were
159 classified as follows: >0.90, excellent reliability; between 0.75 and 0.9, good reliability; between 0.5 and 0.75,
160 moderate reliability; and <0.5, poor reliability.²⁴

161 With a power of 80% and $\alpha = 0.05$, the sample size was determined to detect the correlation coefficient
162 ($r \geq 0.45$, corresponding to a moderate-to-large effect size) between PKA and KAM peaks.

163

164 **Results**

165 In total, 54 patients were analyzed. The mean HKA, PKA, gait speed, and first and second knee adduction moment
166 peak significantly changed after HTO ($P < 0.01$ in all categories) (Table 2). The mean and standard deviation of
167 postoperative HKA and PKA were 3.6° and 1.4° and 7.9° and 1.9° , respectively. The total and subscale scores of
168 the KSS improved significantly after HTO (Table 2). Postoperative PKA was negatively correlated with HKA (r
169 $= -0.42$, $P < 0.01$) (Figure 3A). HKA was weakly associated with the first ($r = -0.33$, $P < 0.01$) and second ($r =$
170 -0.27 , $P = 0.01$) KMA peaks. PKA was moderately correlated with the first ($r = 0.45$, $P < 0.01$) and second ($r =$
171 -0.45 , $P < 0.01$) KAM peaks before HTO. Postoperative HKA was not significantly associated with KAM peaks
172 ($r = -0.26$, not significant in the first peak, $r = -0.20$, not significant in the second peak) after HTO (Figures 3B,
173 3C). However, postoperative PKA was moderately correlated with KAM peaks after HTO ($r = -0.51$, $P < 0.01$, in
174 the first peak; $r = -0.56$, $P < 0.01$) (Figures 3D, 3E). Simple linear regression analysis showed a body weight \times
175 height ($Bw \times Ht$) reduction in KAM peaks for every 1° reduction in postoperative PKA. Postoperative PKA
176 showed variances of 25% and 31% in the postoperative first and second KAM peaks, respectively. After adjusting
177 for age, sex, and baseline gait speed, multivariate linear regression analysis revealed that postoperative PKA was
178 still associated with the first (β coefficient = 0.22, $P < 0.01$) and second ($\beta = 0.20$, $P < 0.01$) KAM peaks after
179 HTO (Table 3).

180 Regarding PROMs, preoperative HKA, PKA, and KAM peaks were not correlated with the total
 181 preoperative KSS and each KSS subscale before HTO. Only postoperative PKA was significantly and negatively
 182 correlated with the postoperative KSS satisfaction subscale ($r = -0.30$, $P = 0.03$) (Table 4). Based on further
 183 analysis of the association between PKA and KSS symptoms and satisfaction subscales, the postoperative PKA
 184 was significantly correlated with satisfaction with pain at rest (Table 5).

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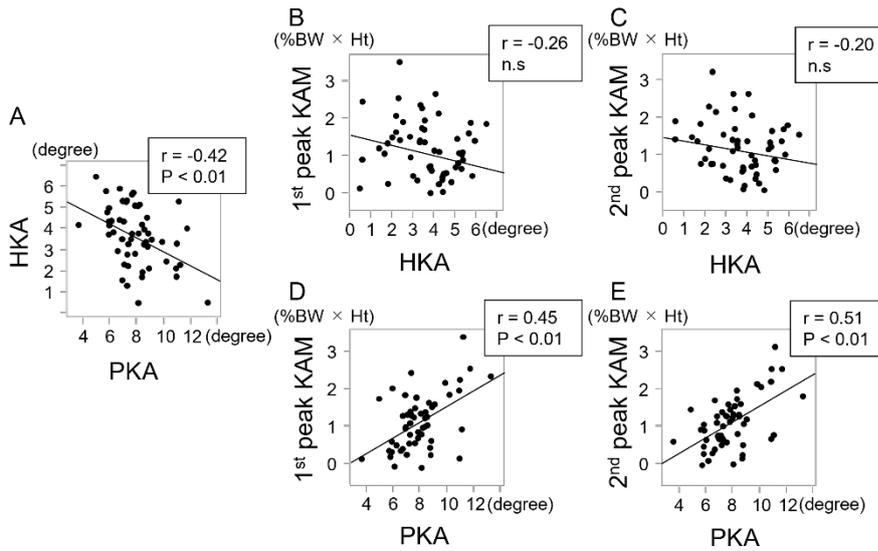
186 Table 2. Gait speed, radiographic characteristics, and clinical outcomes^a

	Patients preoperative OA (n = 54)	with Patients postoperative OA (n = 54)	with P value
HKA, degree	-4.0 ± 2.3	3.6 ± 1.4	<0.001
PKA, degree	15.1 ± 2.2	7.9 ± 1.9	<0.001
Gait speed, m/s	1.2 ± 0.2	1.3 ± 0.2	<0.001
Knee adduction moment			
First peak, %BW × Ht	2.5 ± 0.8	1.1 ± 0.8	<0.001
Second peak, %BW × Ht	2.4 ± 0.8	1.1 ± 0.7	<0.001
Knee Society Score			
Total (range: 0–200)	90.7 ± 21.2	132.9 ± 23.1	<0.001
Symptom (0–25)	11.9 ± 5.5	20.6 ± 4.3	<0.001
Satisfaction (0–40)	13.8 ± 5.0	25.6 ± 8.3	<0.001
Expectation (0–15)	12.7 ± 1.9	9.4 ± 2.6	<0.001
Functional activity (0–100)	52.3 ± 15.5	77.3 ± 14.6	<0.001

187 ^aData were expressed as mean ± standard deviation unless otherwise stated.

188 HKA, hip–knee–ankle angle; PKA, pelvic–knee–ankle angle; BW, body weight; Ht, height

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191 **Figure 3.** Single regression analysis of HKA, PKA, and KAM peaks after HTO. **A:** PKA and HKA. **B:** HKA and
 192 the first KAM peak. **C:** HKA and the second KAM peak. **D:** PKA and the first KAM peak (regression equation;
 193 $-0.21 \times \text{PKA} = -0.58$). **E:** PKA and the second KAM peak ($0.21 \times \text{PKA} = -0.61$). HKA, hip-knee-ankle angle;
 194 PKA, pelvis-knee-ankle angle; KAM, knee adduction moment; BW, body weight; Ht, height

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196 **Table 3.** Multivariate linear regression analysis of knee adduction moment peaks after HTO

	First KAM peak		95% CI		Second KAM peak		95% CI	
	β coefficient	P value	Lower	Upper	β coefficient	P value	Lower	Upper
PKA	0.22	<0.01	0.11	0.32	0.20	<0.01	0.11	0.30
Age	-0.01	0.56	-0.26	0.32	-0.01	0.57	-0.04	0.02
Sex	-0.03	0.88	-0.43	0.36	0.10	0.67	-0.28	0.42
Gait speed	0.56	0.35	-0.63	1.75	0.10	0.78	-0.90	1.21
OA grade	-0.18	0.85	-0.26	0.32	-0.19	0.89	-0.23	0.27

197 PKA, pelvic-knee-ankle angle; KAM, knee adduction moment; n.s., not significant

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199 **Table 4.** Correlation coefficient between postoperative HKA, PKA, and KAM peaks and patient-reported outcome
 200 measures after HTO

HKA	PKA	First KAM	Second KAM
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					peak		peak	
	r	P value						
Knee Society Score								
Total	0.06	0.65	-0.15	0.28	0.10	0.48	0.09	0.54
Symptom	0.05	0.71	-0.02	0.88	-0.04	0.76	0.12	0.37
Satisfaction	0.12	0.38	-0.30	0.03	-0.07	0.63	-0.12	0.39
Expectation	-0.02	0.89	0.07	0.60	0.19	0.16	0.07	0.61
Functional activity	0.02	0.88	-0.08	0.59	0.16	0.29	0.15	0.28

201 HKA, hip-knee-ankle angle; PKA, pelvic-knee-ankle angle; KAM, knee adduction moment; n.s., not significant

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203 **Table 5.** Correlation coefficient between postoperative PKA and satisfaction subscale of the Knee Society Score

Knee Society Score	PKA	
Symptom subscale	r	p
1-Pain with level walking	0.06	0.67
2-Pain with stairs or inclines	-0.10	0.48
3-Does this knee feel “normal” to you?	-0.01	0.96
Satisfaction subscale score	r	p
1-Pain level while sitting	-0.31	0.02
2-Pain level while lying in bed	-0.27	0.05
3-Function while getting out of bed	-0.29	0.03
4-Function while performing household duties	-0.22	n. s.
5-Function while performing recreational activities	-0.23	n. s.

204 PKA, pelvic-knee-ankle angle; n.s., not significant

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206 The intrarater, interrater, and interradiograph reliabilities of HKA (0.975, 0.948, and 0.922, respectively) and PKA
207 (0.978, 0.952, and 0.933, respectively) on a full-length standing anteroposterior radiograph in the bipedal standing
208 position were excellent.

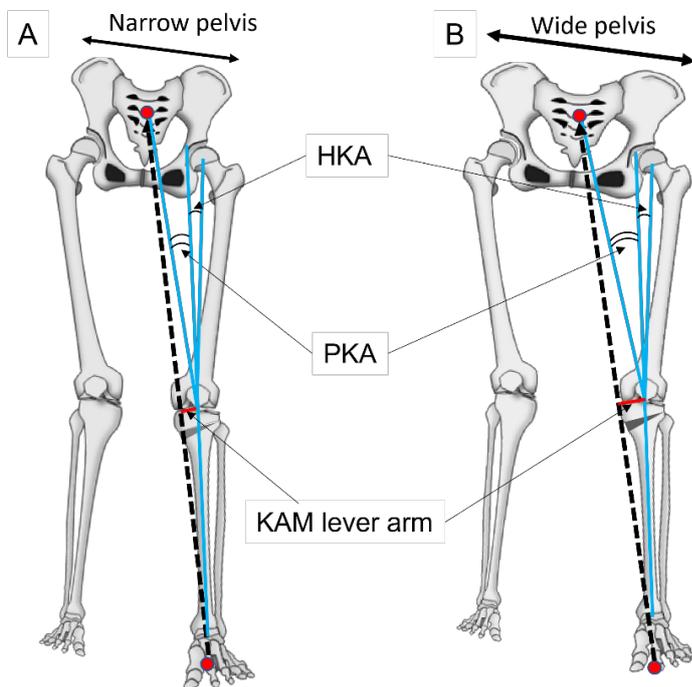
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210 **Discussion**

211 The most important findings of the current study are as follows: PKA was significantly correlated with KAM
212 peaks in patients with varus knee OA after HTO. Further, only PKA was associated with the KSS satisfaction
213 subscale.

214 The product of ground reaction force (GRF) and the lever arm is the moment. The KAM lever arm is
215 an important variable in the examination of knee OA because the association between KAM peaks and the KAM
216 lever arm was higher than that between KAM peaks and frontal plane GRF.¹⁵ The simplified schema presenting
217 the association between the KAM lever arm and PKA and KAM on a one-leg standing radiograph indicated that
218 the KAM lever arm was influenced by leg alignment and pelvic width (Figures 1, 4A, and 4B). PKA could reflect
219 leg alignment, pelvic width, and KAM lever arm. Meanwhile, HKA reflects leg alignment alone (Figure 1). After
220 HTO, HKA was within the range aimed at by the surgeon. However, PKA varied based on pelvic width.
221 Consequently, PKA was the main variable in the KAM lever arm (Figures 4A and 4B). Therefore, there might be
222 a significant correlation between KAM peaks and PKA, but not with HKA, after HTO. A meta-analysis revealed
223 that postoperative leg alignment was not associated with the change in KAM after HTO,²² thereby supporting our
224 results.

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227 **Figure 4.** Association between KAM lever arm and PKA after HTO on a one-foot standing radiograph. **A.**
228 Participant with a narrow pelvis. **B.** Participant with a wide pelvis. HKA, hip–knee–ankle angle; PKA, pelvis–
229 knee–ankle angle; KAM, knee adduction moment; HTO, high tibial osteotomy.

230 Leg alignment is a factor affecting KAM in patients with and without knee OA.^{3, 17} Previous studies
231 reported a significant correlation between leg alignment and KAM before and after HTO.^{7, 37} However, our study
232 showed that HKA was correlated with KAM peaks before but not after HTO. The variance of the postoperative
233 HKA was smaller (standard deviation: 1.4°) than that of previous studies (3°).^{7, 37} KAM peaks were associated
234 with postoperative HKA. However, there is no correlation between HKA and KAM peaks. This finding could be
235 attributed to the small variance of postoperative HKA.

236 KAM is a surrogate of medial compartment loading.⁴ However, a musculoskeletal simulation study
237 reported that KAM reduction could not accurately explain the medial compression force.^{9, 36} An *in vivo* study
238 using force-measuring knee implants showed that KAM could not account for medial compartment loading at
239 all.³⁸ In contrast, another study revealed a high correlation between KAM and mediolateral load distribution.²⁵
240 Therefore, the higher correlation between PKA and KAM must be interpreted with caution bearing in mind that
241 PKA was associated with mediolateral load distribution but not with medial compartment loading.

242 Regression analysis showed a 0.21% Bw × Ht reduction in KAM peaks for every 1° reduction in
243 postoperative PKA. Hence, a 2° difference in PKA, which is equivalent to one standard deviation (SD) of
244 postoperative PKA (1.9°), corresponded to 0.42% Bw × Ht in KAM peaks. Considering that the mean change in
245 KAM peaks before and after HTO was 1.4% Bw × Ht, one SD difference in PKA accounted for approximately
246 30% of the change in KAM peaks. Thus, PKA is an important variable in postoperative mediolateral loading
247 distribution.

248 A previous study on patients with a force-measuring knee implant reported significant correlations
249 between the mediolateral load distribution and the external frontal plane lever arm (EFL), defined as the
250 perpendicular line from the center of the knee joint to the line connecting the center of the ankle joint and the
251 symphysis pubis.⁶ These results supported the notion that the correlation between PKA and KAM peaks was
252 higher than that between PKA and HKA before and after HTO because the concept of EFL when reflecting pelvic
253 width is similar to PKA.

254 HTO can realign the knee joint and change the mediolateral load distribution across the knee joint.^{1, 3, 9}
255 Hence, the load distribution is a key factor for a successful HTO. However, most surgeons could not identify the
256 load distribution because only a few institutions could perform this analysis using a three-dimensional gait
257 analysis system equipped with force plates and motion sensors. While PKA was significantly correlated with
258 KAM after HTO, no association was observed between HKA and KAM. Hence, PKA, but not HKA, reflected the
259 load distribution. Using PKA in HTO planning or evaluation, surgeons could perform HTO or evaluate

260 postoperative outcomes with consideration of mediolateral load distribution. This could eventually lead to
261 improvements in HTO outcomes.

262 Pain during rest and activities is the primary complaint of patients with unicompartmental femorotibial
263 OA. In this study, postoperative PKA was associated with PROMs. However, neither postoperative KAM peaks
264 nor HKA was correlated with satisfaction based on the KSS subscale. On further analysis, PKA was negatively
265 associated with satisfaction with pain at rest, confirming the correlation of postoperative PKA with pain at rest.
266 Pain during activities was evaluated using the KSS symptom subscale (0–25 points), and at a score of 24.9, +1
267 SD of the postoperative symptom subscale was assigned, thereby demonstrating a ceiling effect as the distribution
268 of the scores for the postoperative symptom subscale skewed toward high scores. This made it difficult to
269 determine the relationship between pain in dynamic and PKA, and thus, the correlation between PKA and pain in
270 a dynamic setting was not validated in this analysis.

271 The current study had several limitations. First, PKA was a two-dimensional parameter at rest. It could
272 not reflect dynamic factors, such as postural change during walking. However, the correlation between PKA and
273 KAM peaks was higher than that between PKA and HKA. Moreover, it was an easy-to-use and convenient
274 parameter for predicting outliers in KAM peaks with average leg alignment after HTO. Second, when standing
275 on one leg, the center of mass is anterior to the second sacral vertebra.³² As a result, the correlation between PKA
276 and KAM differs between the one-leg standing radiograph and the bipedal standing radiograph. However, one-
277 leg standing radiographs can be difficult to obtain in elderly patients due to knee pain and/or quadriceps
278 weakness.¹⁶ Therefore, a full-length standing anteroposterior radiograph in the bipedal standing position was
279 performed to assess PKA and HKA while prioritizing radiograph reproducibility in this study. Third, PKA could
280 not reflect the influence of foot alignment on KAM on full-length standing anteroposterior radiographs of the
281 lower limb.^{8, 17, 20} A hip-to-calcaneus radiograph was useful for evaluating whole-leg and foot alignment.¹³ Further
282 studies using hip–knee–calcaneus radiographs should investigate the association between KAM and lower body
283 alignment, including the pelvis, hip, knee, ankle, and foot. Given the above limitations, it should be kept in mind
284 that PKA does not explain all the variation in KAM. Fourth, this study was retrospective in nature. and thus, had
285 a low level of evidence, unlike prospective studies. However, this study is the first to report that the correlation
286 between PKA and KAM was higher than that between PKA and HKA. Hence, our findings could serve as a
287 reference for future prospective studies using PKA in planning knee osteotomy.

288 In conclusion, PKA was significantly correlated with KAM peaks and patient-reported outcomes in
289 patients with varus knee OA before and after HTO. However, HKA was not correlated with KAM peaks after

290 HTO. Hence, more attention should be paid to the distribution of mediolateral loading after HTO, and PKA could
291 be a potential radiographic parameter in HTO planning with consideration of postoperative mediolateral load
292 distribution.

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