Knee Adduction Moment during Gait vs. Radiographic Alignment Parameters: HTO Optimal Target from a Dynamic Perspective

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Disclosure

We have nothing to disclose.

Background

❖ Knee adduction moment (KAM)

- Medial compartment loading (Zhao et al., 2007)
- OA progression (Miyazaki et al., 2002)
- OA severity (Sharma et al., 1998; Kean et al., 2012)

❖ Surgical planning for HTO

- Approached from radiological perspective (e. g. Miniaci's and Dugdale's methods)

❖ Conventional valgus overcorrection

- Knee joint line abnormality (Kim et al., 2022)
- Lateral hinge fracture (Lee et al., 2018)
- Leg length difference (Lee et al., 2019)
- Patellar height change (Bin et al., 2016; Gaasbeek et al., 2007)
- Decreased functional outcome (Kim et al., 2022; Lee et al., 2019)

Purpose

❖ To analyze alignment parameters associated with the KAM variables from a random population

❖ To investigate the optimal correction amount in HTO using gait analysis

Material and methods

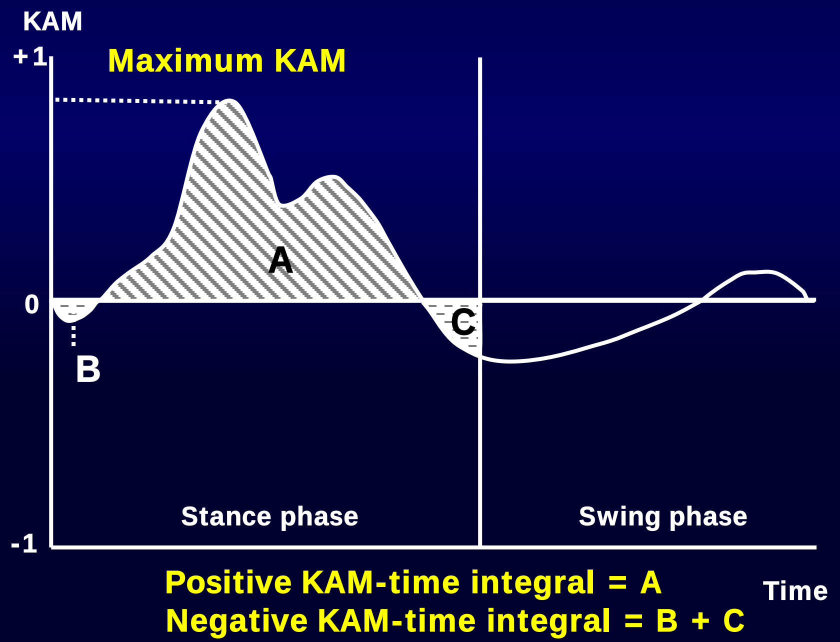
- Population
  - 500 participants
  - 10 to 75 years old
  - Randomly selected from the city of Seongnam
- Gait analysis
  - Positive/negative KAM-time integral [N·m·s/kg]
  - Maximum KAM [N·m/kg]
- Statistical analysis
  - Chi-square test or Fisher's exact test, t-test, and ANOVA (Bonferroni post-hoc test)
  - Correlation analyses
  - Multiple linear regression
  - Interobserver reliability test using intraclass correlation coefficients (ICCs)

Total lower extremities from 500 participants (N=1000)

→ Excluded:
- **Excessive patellar rotation in radiographs (N=57)**
- **Marker mismatch in gait analysis (N=6)**

↓

Lower extremities included in the analysis (N=937)



Population characteristics

No.	937
Age (years)	36.8 (SD, ±16.5)
Sex (men:women)	471:466 (50.3%:49.7%)
Side (right:left)	470:467 (49.8%:50.2%)
Height (cm)	165.8 (SD, ±8.9)
Weight (kg)	64.0 (SD, ±12.8)
BMI (kg/m2)	23.1 (SD, ±3.4)
Kinetic data	
Maximum KAM (Nm/kg)	0.36 (SD, ±0.12)
Positive KAM-time integral (Nms/kg)	0.13 (SD, ±0.05)
Negative KAM-time integral (Nms/kg)	0.0039 (SD, ±0.010)
Radiographic measurements	
Medial K-L grade (0/I/II/III/IV)	780/139/17/1/0 (83.2%/14.8%/1.8%/0.1%/0%)
Lateral K-L grade (0/I/II/III/IV)	856/77/4/0/0 (91.4%/8.2%/0.4%/0%/0%)
mTFA (°)	1.16 (SD, ±2.50)
MPTA (°)	86.2 (SD, ±2.19)
LDFA (°)	86.8 (SD, ±2.05)
KJLO (°)	1.46 (SD, ±2.21)
AJLO (°)	-2.44 (SD, ±3.96)
JLCA (°)	0.53 (SD, ±1.40)
Tibiofemoral translation	3.24 (SD, ±2.50)

Factors associated with KAM variables in correlation study

	Age	Sex	Height	Weight	BMI	K-L grade (medial)	K-L grade (lateral)	mTFA	MPTA	LDFA	KJLO	AJLO	JLCA	Tibiofemoral translation
Positive KAM-time integral	**0.145**	**-0.125**	0.054	0.015	-0.004	**0.140**	**0.088**	**0.376**	**-0.240**	**0.184**	0.036	**-0.258**	-0.011	0.036
	(<0.001)	**(<0.001)**	(0.097)	(0.645)	(0.907)	**(<0.001)**	**(0.007)**	**(<0.001)**	**(<0.001)**	**(<0.001)**	(0.266)	**(<0.001)**	(0.729)	(0.274)
Negative KAM-time integral	-0.064	0.064	-0.014	-0.038	-0.052	-0.026	-0.048	**-0.095**	**0.076**	-0.060	-0.037	0.034	0.037	-0.059
	(0.050)	(0.050)	(0.669)	(0.251)	(0.113)	(0.435)	(0.140)	**(0.003)**	**(0.021)**	(0.065)	(0.254)	(0.301)	(0.253)	(0.069)
Maximum KAM	**0.103**	**-0.087**	0.016	-0.019	-0.021	**0.106**	0.056	**0.383**	**-0.250**	**0.199**	0.026	**-0.269**	-0.031	0.025
	(0.002)	**(0.008)**	(0.628)	(0.559)	(0.515)	**(0.001)**	(0.085)	**(<0.001)**	**(<0.001)**	**(<0.001)**	(0.434)	**(<0.001)**	(0.336)	(0.451)

mTFA had the strongest correlation with both the positive KAM-time integral and the maximum KAM (r=0.376 and 0.383, respectively) followed by AJLO (r=-0.258 and -0.269).

Independent explanatory factors for KAM variables

Positive KAM-time integral	Non-standardized		Standardized β	P-value	VIF
	β	SE			
Sex (M: 0, F: 1)	-0.009	0.003	-0.087	0.005	1.097
Medial K-L grade	0.012	0.004	0.096	0.002	1.084
mTFA	0.006	0.001	0.256	<0.001	1.663
MPTA	-0.002	0.001	-0.076	0.036	1.498
AJLO	-0.003	0.000	-0.206	<0.001	1.077

R^2=0.1917, adjusted R^2=0.1874

Maximum KAM	Non-standardized		Standardized β	VIF
	β	SE		
mTFA	0.017	0.001	0.342	1.686
AJLO	-0.006	0.001	-0.198	1.064

R^2 = 0.1843, adjusted R^2=0.1825

Negative KAM-time integral	Non-standardized		Standardized β	P-value
	β	SE		
mTFA	-0.0004	0.0001	-0.0955	0.0034

R^2 = 0.0091, adjusted R^2 = 0.0081

ANOVA: KAM variables ~ alignment groups of 1° interval

Varus

0°

Valgus

mTFA	No.	Age (years)	Positive KAM-time Integral (Nms/kg)	Negative KAM-time Integral (Nms/kg)	Maximum KAM (Nm/kg)
≥10	1	59.0	0.266	0.000	0.656
[9, 10)	1	61.0	0.194	0.000	0.492
[8, 9)	1	61.0	0.254	0.000	0.658
[7, 8)	9	49.6	0.193 (SD, ±0.071)	0.001 (SD, ±0.002)	0.478 (SD, ±0.145)
[6, 7)	18	48.7	0.181 (SD, ±0.062)	0.002 (SD, ±0.003)	0.479 (SD, ±0.139)
[5, 6)	15	43.7	0.174 (SD, ±0.062)	0.007 (SD, ±0.019)	0.441 (SD, ±0.115)
[4, 5)	73	42.2	0.164 (SD, ±0.051)	0.003 (SD, ±0.006)	0.429 (SD, ±0.101)
[3, 4)	103	39.8	0.153 (SD, ±0.054)	0.003 (SD, ±0.006)	0.407 (SD, ±0.120)
[2, 3)	131	36.7	0.142 (SD, ±0.055)	0.003 (SD, ±0.007)	0.383 (SD, ±0.115)
[1, 2)	138	39.9	0.136 (SD, ±0.051)	0.003 (SD, ±0.013)	0.373 (SD, ±0.121)
[0, 1)	141	36.0	0.128 (SD, ±0.047)	0.005 (SD, ±0.011)	0.350 (SD, ±0.103)
[-1, 0)	121	33.2	0.119 (SD, ±0.043)	0.005 (SD, ±0.012)	0.334 (SD, ±0.105)
[-2, -1)	86	32.8	0.108 (SD, ±0.042)	0.004 (SD, ±0.009)	0.308 (SD, ±0.099)
[-3, -2)	59	30.4	0.104 (SD, ±0.045)	0.006 (SD, ±0.014)	0.293 (SD, ±0.121)
[-4, -3)	22	26.8	0.097 (SD, ±0.037)	0.007 (SD, ±0.010)	0.289 (SD, ±0.089)
[-5, -4)	13	29.8	0.096 (SD, ±0.074)	0.006 (SD, ±0.011)	0.265 (SD, ±0.121)
[-6, -5)	2	41.0	0.156 (SD, ±0.066)	0.001 (SD, ±0.001)	0.397 (SD, ±0.146)
[-7, -6)	1	23.0	0.328	0.000	0.600
[-8, -7)	2	23.5	0.078 (SD, ±0.046)	0.004 (SD, ±0.005)	0.221 (SD, ±0.100)
Total	937				

The positive KAM-time integral and the maximum KAM increased as the amount of varus increased ($P < 0.001$).
There was no significant increasing tendency of the negative KAM-time integral as the amount of valgus increased.

Post-hoc analysis: <u>**the positive KAM-time integral**</u>

~ alignment groups of 1° interval

Varus ← 0° → Valgus

Varus 8° | Varus 3° | Valgus 5°

mTFA	≥10	[9, 10)	[8, 9)	[7, 8)	[6, 7)	[5, 6)	[4, 5)	[3, 4)	[2, 3)	[1, 2)	[0, 1)	[-1, 0)	[-2, -1)	[-3, -2)	[-4, -3)	[-5, -4)	[-6, -5)	[-7, -6)
≥10																		
[9, 10)	-0.072 (1.000)																	
[8, 9)	-0.011 (1.000)	-0.060 (1.000)																
[7, 8)	-0.073 (1.000)	0.001 (1.000)	0.061 (1.000)															
[6, 7)	-0.085 (1.000)	0.013 (1.000)	0.073 (1.000)	0.012 (1.000)														
[5, 6)	-0.091 (1.000)	0.019 (1.000)	0.080 (1.000)	0.019 (1.000)	0.006 (1.000)													
[4, 5)	-0.101 (1.000)	0.030 (1.000)	0.090 (1.000)	0.029 (1.000)	0.017 (1.000)	0.010 (1.000)												
[3, 4)	-0.113 (1.000)	0.041 (1.000)	0.101 (1.000)	0.040 (1.000)	0.028 (1.000)	0.021 (1.000)	0.011 (1.000)											
[2, 3)	-0.124 (1.000)	0.052 (1.000)	0.113 (1.000)	0.052 (0.503)	0.039 (0.318)	0.033 (1.000)	0.023 (0.344)	0.012 (1.000)										
[1, 2)	0.129 (1.000)	0.058 (1.000)	0.118 (1.000)	0.057 (0.173)	0.045 (0.067)	0.038 (0.874)	0.028 (0.020)	0.017 (1.000)	0.005 (1.000)									
[0, 1)	0.138 (1.000)	0.066 (1.000)	0.127 (1.000)	0.065 (0.027)	0.053 (0.004)	0.047 (0.104)	0.037 (<0.001)	0.025 (0.016)	0.014 (1.000)	0.009 (1.000)								
[-1, 0)	0.146 (0.638)	0.075 (1.000)	0.135 (1.000)	0.074 (0.004)	0.062 (<0.001)	0.055 (0.011)	0.045 (<0.001)	0.034 (<0.001)	0.022 (0.075)	0.017 (1.000)	0.008 (1.000)							
[-2, -1)	0.157 (0.315)	0.086 (1.000)	0.146 (0.662)	0.085 (<0.001)	0.073 (<0.001)	0.066 (<0.001)	0.056 (<0.001)	0.045 (<0.001)	0.033 (<0.001)	0.028 (0.009)	0.019 (0.791)	-0.011 (1.000)						
[-3, -2)	0.161 (0.249)	0.090 (1.000)	0.150 (0.529)	0.089 (<0.001)	0.077 (<0.001)	[illegible]	0.060 (<0.001)	0.049 (<0.001)	0.037 (<0.001)	0.032 (0.008)	0.023 (0.456)	-0.015 (1.000)	[illegible]					
[-4, -3)	0.169 (0.178)	0.097 (1.000)	0.157 (0.383)	0.096 (<0.001)	0.084 (<0.001)	0.077 (0.001)	0.067 (<0.001)	0.056 (<0.001)	0.045 (0.021)	0.039 (0.119)	0.031 (1.000)	-0.022 (1.000)	-0.011 (1.000)	-0.007 (1.000)				
[-5, -4)	0.169 (0.201)	0.098 (1.000)	0.158 (0.423)	0.097 (0.002)	0.085 (0.001)	0.078 (0.007)	0.068 (0.001)	0.057 (0.022)	0.045 (0.334)	0.040 (1.000)	0.031 (1.000)	-0.023 (1.000)	-0.012 (1.000)	-0.008 (1.000)	-0.001 (1.000)			
[-6, -5)	0.109 (1.000)	0.037 (1.000)	0.098 (1.000)	0.037 (1.000)	0.024 (1.000)	0.018 (1.000)	0.008 (1.000)	-0.003 (1.000)	-0.015 (1.000)	-0.020 (1.000)	-0.029 (1.000)	0.037 (1.000)	0.048 (1.000)	0.052 (1.000)	0.059 (1.000)	0.060 (1.000)		
[-7, -6)	-0.063 (1.000)	-0.135 (1.000)	-0.074 (1.000)	-0.135 (1.000)	-0.148 (0.729)	-0.154 (0.515)	-0.164 (0.202)	-0.175 (0.089)	-0.187 (0.037)	-0.192 (0.024)	-0.201 (0.012)	0.209 (0.006)	0.220 (0.002)	0.224 (0.002)	0.231 (0.001)	0.232 (0.002)	0.172 (0.886)	
[-8, -7)	0.187 (0.405)	0.115 (1.000)	0.176 (0.738)	0.115 (0.605)	0.102 (1.000)	0.096 (1.000)	0.086 (1.000)	0.075 (1.000)	0.063 (1.000)	0.058 (1.000)	0.049 (1.000)	0.041 (1.000)	0.030 (1.000)	0.026 (1.000)	0.019 (1.000)	0.018 (1.000)	0.078 (1.000)	0.250 (0.009)

Varus ↑ 0° ↓ Valgus

Valgus 5°

A

B

(**A**) There was difference of the positive KAM-time integral in lower extremities with 3° to 8° of varus and 0° to 5° of valgus.

(**B**) There was no significant difference within alignment groups of 0° to 5° of valgus.

Post-hoc analysis: **<u>the maximum KAM</u>**
~ alignment groups of 1° interval

mTFA	≥10	[9, 10)	[8, 9)	[7, 8)	[6, 7)	[5, 6)	[4, 5)	[3, 4)	[2, 3)	[1, 2)	[0, 1)	[-1, 0)	[-2, -1)	[-3, -2)	[-4, -3)	[-5, -4)	[-6, -5)	[-7, -6)
≥10																		
[9, 10)	-0.164 (1.000)																	
[8, 9)	0.002 (1.000)	-0.166 (1.000)																
[7, 8)	-0.178 (1.000)	0.014 (1.000)	0.180 (1.000)															
[6, 7)	-0.177 (1.000)	0.013 (1.000)	0.179 (1.000)	-0.001 (1.000)														
[5, 6)	-0.215 (1.000)	0.051 (1.000)	0.217 (1.000)	0.037 (1.000)	0.038 (1.000)													
[4, 5)	-0.227 (1.000)	0.063 (1.000)	0.229 (1.000)	0.050 (1.000)	0.050 (1.000)	0.012 (1.000)												
[3, 4)	-0.249 (1.000)	0.085 (1.000)	0.251 (1.000)	0.071 (1.000)	0.072 (1.000)	0.034 (1.000)	0.021 (1.000)											
[2, 3)	-0.273 (1.000)	0.109 (1.000)	0.275 (1.000)	0.095 (1.000)	0.096 (0.114)	0.058 (1.000)	0.046 (0.917)	0.024 (1.000)										
[1, 2)	0.283 (1.000)	0.119 (1.000)	0.285 (1.000)	0.106 (1.000)	0.106 (0.027)	0.068 (1.000)	0.056 (0.097)	0.035 (1.000)	0.010 (1.000)									
[0, 1)	0.306 (1.000)	0.142 (1.000)	0.308 (1.000)	0.128 (0.153)	0.129 (0.001)	0.091 (0.484)	0.078 (<0.001)	0.057 (0.015)	0.033 (1.000)	0.022 (1.000)								
[-1, 0)	0.322 (0.733)	0.158 (1.000)	0.324 (0.693)	0.144 (0.036)	0.145 (<0.001)	0.107 (0.088)	0.094 (<0.001)	0.073 (<0.001)	0.049 (0.101)	0.038 (1.000)	0.016 (1.000)							
[-2, -1)	0.348 (0.348)	0.184 (1.000)	0.350 (0.328)	0.170 (0.003)	0.171 (<0.001)	0.133 (0.004)	0.121 (<0.001)	0.099 (<0.001)	0.075 (<0.001)	0.065 (0.005)	0.042 (1.000)	-0.026 (1.000)						
[-3, -2)	0.363 (0.227)	0.199 (1.000)	0.365 (0.214)	0.185 (0.001)	0.186 (<0.001)	[illegible]	0.136 (<0.001)	0.114 (<0.001)	0.090 (<0.001)	0.080 (0.001)	0.057 (0.171)	-0.041 (1.000)	[illegible]					
[-4, -3)	0.367 (0.236)	0.203 (1.000)	0.369 (0.222)	0.189 (0.004)	0.190 (<0.001)	0.152 (0.009)	0.140 (<0.001)	0.118 (0.001)	0.094 (0.048)	0.084 (0.201)	0.061 (1.000)	-0.045 (1.000)	-0.019 (1.000)	-0.004 (1.000)				
[-5, -4)	0.391 (0.133)	0.227 (1.000)	0.393 (0.125)	0.213 (0.002)	0.214 (<0.001)	0.176 (0.006)	0.164 (<0.001)	0.142 (0.003)	0.118 (0.050)	0.108 (0.157)	0.085 (1.000)	-0.070 (1.000)	-0.043 (1.000)	-0.028 (1.000)	-0.024 (1.000)			
[-6, -5)	0.259 (1.000)	0.095 (1.000)	0.261 (1.000)	0.081 (1.000)	0.082 (1.000)	0.044 (1.000)	0.032 (1.000)	0.010 (1.000)	-0.014 (1.000)	-0.024 (1.000)	-0.047 (1.000)	0.063 (1.000)	0.089 (1.000)	0.104 (1.000)	0.108 (1.000)	0.132 (1.000)		
[-7, -6)	0.056 (1.000)	-0.108 (1.000)	0.058 (1.000)	-0.122 (1.000)	-0.121 (1.000)	-0.159 (1.000)	-0.171 (1.000)	-0.193 (1.000)	-0.217 (1.000)	-0.227 (1.000)	-0.250 (1.000)	0.266 (1.000)	0.292 (1.000)	0.307 (1.000)	0.311 (1.000)	0.335 (0.678)	0.203 (1.000)	
[-8, -7)	0.435 (0.263)	0.271 (1.000)	0.437 (0.251)	0.257 (0.568)	0.258 (0.345)	0.220 (1.000)	0.208 (1.000)	0.186 (1.000)	0.162 (1.000)	0.152 (1.000)	0.129 (1.000)	0.113 (1.000)	0.087 (1.000)	0.072 (1.000)	0.068 (1.000)	0.044 (1.000)	0.176 (1.000)	0.379 (0.985)

Varus ← 0° → Valgus
Varus 8°
Varus 3°
Valgus 5°
Varus
0°
Valgus
Valgus 5°
A
B

(**A**) There was difference of the maximum KAM in lower extremities with 3° to 8° of varus and 0° to 5° of valgus.

(**B**) There was no significant difference within alignment groups of 0° to 5° of valgus.

Discussion

- Radiographic variables
  - mTFA and AJLO had the strongest correlation with the KAM variables in a general population (in varus OA: Lee et al., 2021)
  - Role of HTO in compensatory ankle joint line valgization (Lee et al., 2015; Kim et al., 2020)

- No significant association between correction amount and difference in the KAM before and after HTO (Kim et al., 2019)

- Further research needed to reveal the relationship between the amount of valgus and the negative KAM-time integral

Conclusion

- mTFA and AJLO are the main explanatory variables for the KAM variables.

- Correction to at least neutral alignment in HTO might suffice biomechanically while valgus overcorrection provides no additional gain in reducing the KAM.

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