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KNEE ARTHROPLASTY

Risk factors of hyperextension and its relationship with the clinical outcomes following mobile-bearing total knee arthroplasty

Han-Jun Lee[1] · Yong-Beom Park[1] · Dong-Hoon Lee[1] · Kyu-Hwang Kim[1] · Dae Woong Ham[1] · Seong Hwan Kim[1,2]

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Abstract

Introduction To evaluate the incidence and risk factors of postoperative hyperextension after mobile-bearing total knee arthroplasty (TKA) and its clinical outcomes.

Materials and methods This retrospective case–control study included 387 knees of primary TKA patients after a 5-year follow-up. The clinical outcomes and radiographs including posterior condylar offset (PCO), femur and tibial slope angle and its discrepancy were evaluated. The patients were divided into two groups (group 1: non-hyperextension, group 2: hyperextension). An extension greater than 5° measured using a goniometer at the final follow-up was defined as hyperextension. Logistic and linear regression analyses were performed.

Results Overall, 43 knees (11.1%) with hyperextension were observed at the last follow-up. There was no significant difference between groups in terms of the clinical outcomes although the functional scores were worse in group 2. There was no significant difference in the postoperative radiologic evaluation except for a change in PCO (group 1 vs. group 2; − 0.2 mm ± 3.8 vs. − 2.4 mm ± 3.0, $p = 0.003$), distal femoral resection slope angle (− 9.1° ± 2.1 vs. − 12.1° ± 1.7, $p < 0.000$) and discrepancy of the slope angle (0.3° ± 4.5 vs. − 3.6° ± 3.9, $p < 0.000$). The change in PCO [odds ratio (OR) 0.86, $p = 0.012$], discrepancy of the slope angle (OR 0.8136, $p = 0.000$) and the preoperative mechanical femorotibial angle (OR 1.09, $p = 0.003$) were associated with hyperextension.

Conclusion Mobile-bearing TKA with hyperextension over 5° showed worse functional outcomes at the mid-term follow-up, even though no serious complications were observed. Care should be taken to maintain the posterior condylar offset and to match the resection angles in femur and tibia due to the risk of hyperextension and worse functional outcomes.

Level of evidence IV.

Keywords Total knee arthroplasty · Mobile bearing · Hyperextension · Posterior condylar offset · Slope discrepancy

Introduction

Total knee arthroplasty (TKA) has been showing successful pain relief and functional improvement in patients with advanced osteoarthritis (OA) [1–3]. The outcomes of TKA are associated with several factors including patients, prosthetic design and surgical techniques. Range of motion (ROM) is regarded as one of the most important factors affecting the clinical outcomes after TKA. Especially, hyperextension after TKA has been associated with poor clinical outcomes [4, 5]. In the case of hyperextension, a patient will continue to force the knee into hyperextension to help stabilize the limb during the stance phase of the gait cycle, thus resulting in fatigue of the quadriceps muscles [6]. Hyperextension after TKA is difficult to correct; therefore, prevention is the best management technique [7, 8]. Great care should be taken to not accept ligament instability with the implant in place, thus resulting in an increased postoperative extension.

A limited number of studies have evaluated the occurrence of hyperextension because it is usually associated with

Han-Jun Lee and Yong-Beom Park contributed equally to this work.

✉ Seong Hwan Kim
ksh170177@nate.com

[1] Department of Orthopedic Surgery, Chung-Ang University College of Medicine , Chung-Ang University Hospital , 102 Heukseok-ro, Dongjak-gu, Seoul 06973, South Korea

[2] Orthopedic Department , Centre Hospitalier de Versailles , Le Chesnay, France

specific conditions, such as valgus deformities, ligamentous laxity, previous high tibial osteotomy (HTO), or neuromuscular disorders such as poliomyelitis [7, 9]. Hyperextension deformity has been associated with decreased load absorption and stiffness, resulting in an increased contact force and posterior capsular laxity even in normal knees [10]. However, only few studies have focused on the role of hyperextension after TKA due to the rarity of the condition [11–14]. Therefore, the incidence of hyperextension and its functional acceptability have not been well documented. Furthermore, there is still no consensus about the risk factors, the definition of hyperextension and its acceptable range after TKA, especially in mobile-bearing systems, although a genu recurvatum greater than 5° has been usually considered as hyperextension after TKA by previous studies [13, 15]. Although mobile-bearing knee designs have been used for more than 30 years [16–18], to the best of our knowledge, however, there is no previous study regarding the clinical outcomes and incidence of postoperative hyperextension after TKA with low contact stress (LCS) mobile-bearing prosthesis.

Therefore, we aimed to investigate the incidence and the factors associated with postoperative hyperextension and its relationship to the clinical outcomes after TKA with mobile-bearing prostheses. It is hypothesized that patients with hyperextension show worsened outcomes than patients without hyperextension. Additionally, a decreased posterior condylar offset (PCO) may potentially affect the degree of hyperextension in a mobile-bearing TKA.

Materials and methods

We retrospectively evaluated a total 484 consecutive patients who underwent primary unilateral TKA from 2008 to 2013. All the patients presented a history of degenerative OA with varus deformity. The exclusion criteria were as follows: (1) varus deformity of more than 20° (18 patients), (2) valgus knees extending greater than the neutral axis (8 patients), (3) osteotomy in the affected limb (13 patients), (4) severe bony defects needing bone grafting (15 patients), (5) preoperative flexion contracture greater than 30° (8 patients), (6) postoperative flexion contracture greater than 10° (9 patients), (7) a body mass index (BMI) of over 30 kg/m^2 (6 patients), (8) presence of clinical general laxity or neuromuscular comorbidity (such as spinal stenosis with evidence of power decrease) (7 patients), (9) cases with acute infections after TKA (2 patients), and (10) inability to attend the scheduled follow-up (32 patients). After the exclusion criteria were applied, a total of 366 patients (387 knees) were included in this study. A LCS rotating platform mobile-bearing total knee system (LCS®, Depuy, Warsaw, IN, USA) was used. At the time of the TKA surgery, the average age was 69.3 years ± 12.5 (range 58–79 years) and patient demographics are summarized in Table 1. The mean follow-up was 65.2 months ± 3.6, while the minimum follow-up was 5 years.

The operations were performed using a mid-vastus approach through a midline skin incision measuring about

Table 1 Preoperative demographic data (mean ± standard deviation)

	Group 1 (non-hyperextension)	Group 2 (hyperextension)	*p* value
Number of cases	344	43	–
Age (years)	68.5 ± 14.3	70.3 ± 8.9	0.421
Body mass index (BMI)	25.8 ± 3.3	25.4 ± 3.8	0.461
Gender (male:female)	58:265	5: 38	0.414
Range of motion			
Flexion contracture	9.2° ± 9.8	10.6° ± 7.2	0.365
Further flexion	126.9° ± 17.9	127.7° ± 12.8	0.776
KSS scores			
KS knee score	45.9 ± 10.7	49.3 ± 13.6	0.058
KS function score	44.8 ± 10.0	42.0 ± 17.2	0.116
HSS score	48.8 ± 13.2	45.5 ± 9.7	0.113
WOMAC total scores	54.7 ± 9.5	52.1 ± 13.2	0.107
Pain	9.4 ± 3.5	8.5 ± 3.9	0.117
Stiffness	4.0 ± 1.4	4.4 ± 1.5	0.081
Function	41.7 ± 10.6	40.2 ± 13.1	0.395
Mechanical femorotibial angle	Varus 10.8° ± 6.7	Varus 14.8° ± 5.5	0.0002
Joint line position (mm)	15.1 ± 3.6	16.1 ± 3.2	0.083
Tibial posterior slope angle	10.9° ± 3.8	10.8° ± 2.8	0.867
Posterior condylar offset (mm)	26.3 ± 3.1	29.5 ± 4.5	0.000

10 cm in length [19]. The cruciate ligaments were excised in all patients. Tibial cutting was initially performed using the extramedullary method followed by a femoral cut using the gap technique with a lamina spreader or gap blocks. Soft tissue balancing was performed using a sequence of tissue releases for medial, lateral, and posterior structures. Adequate soft tissue balancing was achieved and confirmed by palpation of the ligamentous tension and assessment of the gap during symmetrical leg distraction using a laminar spreader. During gap balancing, the mediolateral and flexion–extension gaps were adjusted within 3 mm by a laminar spreader. None of the patients underwent patellar resurfacing. All of the components were fixed with cement.

The patients were evaluated preoperatively and postoperatively at 6 weeks, 3 months, 6 months, and 1 year and annually thereafter. At every visit, an independent experienced research assistant used the Knee Society (KS) scoring system, Hospital for special surgery scoring system (HSS) and Western Ontario and McMaster Universities Index (WOMAC) score, and a senior orthopedic surgeon evaluated the passive, non-weight-bearing ROM measured to the nearest 5° using a goniometer with the patient in a supine position. Goniometers are commonly used to measure ROM and have good to excellent reproducibility [20]. Postoperative complications were also evaluated during the follow-up period. Extensions greater than 5° based on the ROM at the final follow-up were defined as hyperextensions. The patients were divided into two groups based on the hyperextension (non-hyperextension group and hyperextension group) at the final follow-up. Finally, 344 knees in the non-hyperextension group (group 1) and 43 knees in the hyperextension group (group 2) were enrolled in this study.

Radiological evaluation

Full length and standing anteroposterior, lateral, and Merchant's view images were acquired at each follow-up visit and assessed for limb alignment, component positioning, and any features associated with loosening. The standing patient was positioned with both feet in a symmetric internal rotation to bring both patellae into the forward-facing position. The proximal tibial and distal femoral diaphyseal axes, defined as the lines connecting the midpoints of the outer cortical diameter at 5 cm and 15 cm to the joint line, were used to measure the sagittal extension angle (Fig. 1). It remains controversial as to which point or axis reveals the true mechanical axis or ROM; the diaphyseal axis used in this study has a high reproducibility [21–23]. The joint line, mechanical tibiofemoral angle (MAD), and prosthesis alignments were also evaluated. The component positioning including the coronal femoral component angle, coronal tibial component angle, sagittal femoral component angle, and sagittal tibial component angle were evaluated in the coronal and sagittal planes [24] (Fig. 2). The PCO and the change in the PCO [25, 26] were evaluated by determining the difference between the pre- and postoperative values (Fig. 3). The tibial posterior slope (a) and the distal femoral resection slope (b) angles were measured on the lateral radiographs of the knee. Negative values indicated hyperextension. The tibial posterior slope angle (a) was defined as the angle between the undersurface of the tibial component and the line connecting the center of the medullary canal, and the distal femoral resection slope angle (b) was defined as the angle between the undersurface of the distal resection

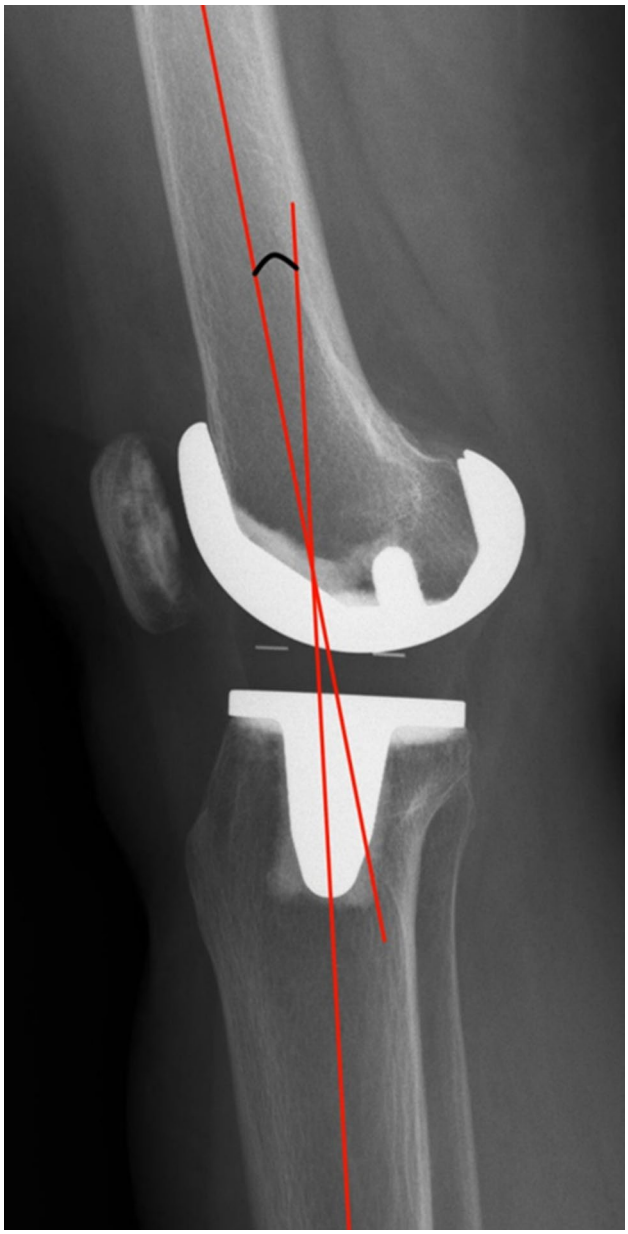

Fig. 1 Radiographic measuring of the extension angle is shown. A line connecting the midpoints of the outer cortical diameter at 5 cm and 15 cm to the joint line was used

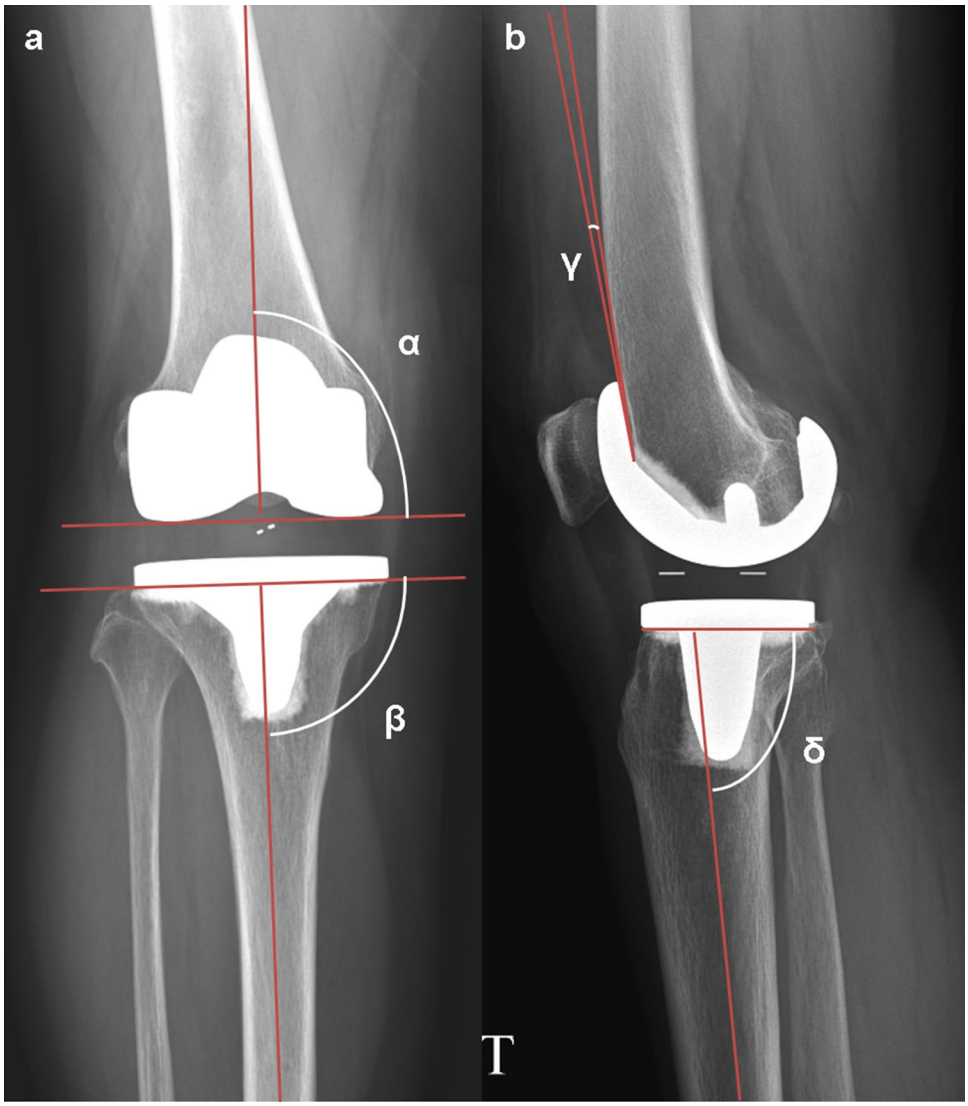

Fig. 2 The measurements of the component are shown

plane of the femoral component and the line connecting the center of the medullary canal (Fig. 4). The discrepancy between these angles ($a+b$) was used to determine whether the femoral component position compensated for the tibial component position or whether it resulted in hyperextension, as denoted by a negative value. All the measurements were performed on a PACS (Picture Archiving and Communications System; General Electric, Chicago, IL, USA) monitor using a mouse point cursor and automated computer calculation and the values were rounded off to two decimal places.

Statistical analysis

Statistical analyses were conducted using SPSS for Windows version 19.0 (SPSS, Chicago, IL, USA) and G*power analysis (ver 3.1.5).

The primary outcome measure of the study was the difference in the mean extension angle after TKA. In the post hoc power analysis using the final extension angle in Table 3, the calculated power was found to be 1.00 with a calculated effect size of 3.6986359 in a two-sided α error of 5% to detect significant differences.

A paired t test, independent t test, or Wilcoxon signed rank test were performed to compare the preoperative and postoperative data or the hyperextension and non-hyperextension group according to the normal distribution in the Shapiro–Wilk's test. Time-dependent data were analyzed with an RM ANOVA, and post hoc comparisons between the mean extension angles of all pairs of points in time were performed. Bonferroni adjustments, including all pairwise comparisons within a specific model, were applied to p values to account for multiple testing. Pearson's correlation coefficient was calculated to evaluate the correlations among the extension angle, radiologic measurements, and clinical outcomes. The statistically significant factors according to the t test or the correlation analysis were used for the logistic regression

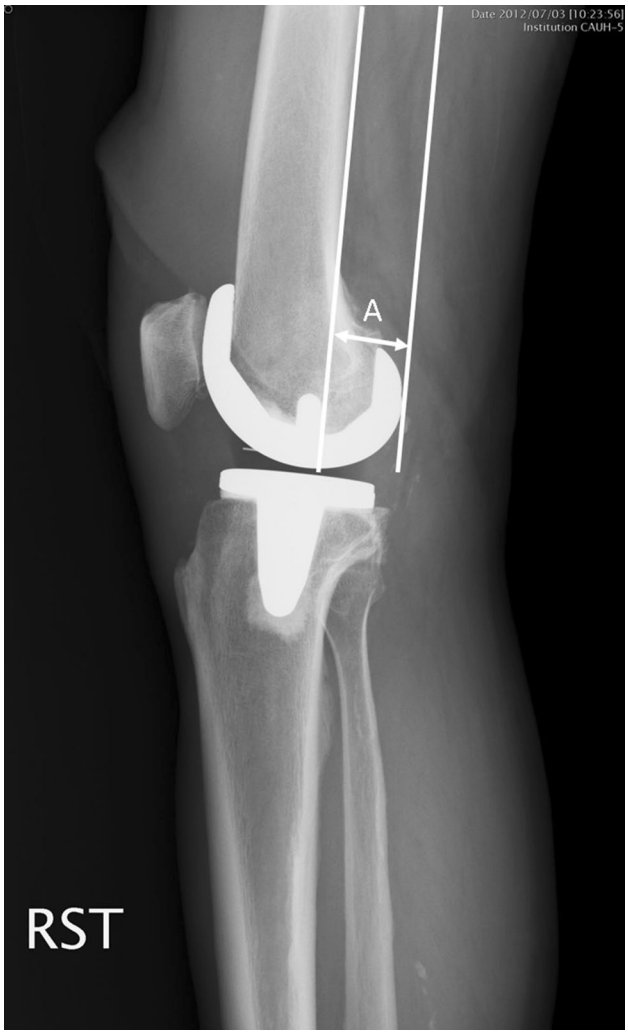

Fig. 3 Radiographic evaluation of the posterior condylar offset (PCO) is shown. The distance between the extension line of the posterior cortex of the femur and its parallel line to the most prominent point of femur condyle was measured

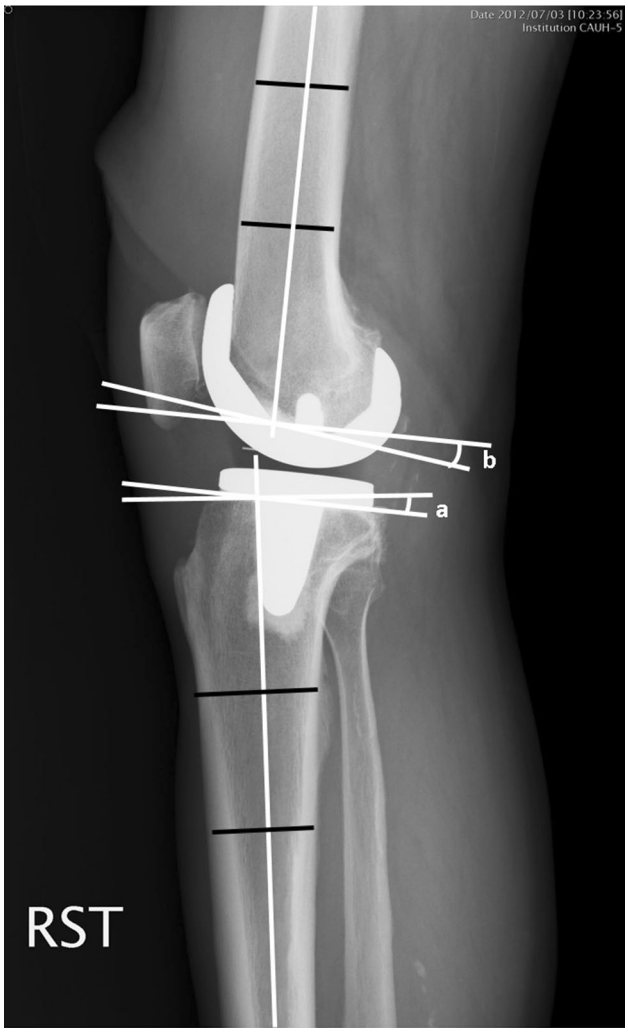

Fig. 4 Tibial posterior slope angle (a) was defined as the angle between the undersurface of the tibial component and the line connecting the center of the medullary canal, distal femoral resection slope angle (b) was defined as the angle between the undersurface of the distal resection plane of the femoral component and the line connecting the center of the medullary canal

analysis including the radiologic measurements. A stepwise logistic regression analysis with backward elimination was performed using the results of the AIC to identify the factors affecting hyperextension after TKA using LCS. Highly associated factors were separately included in the regression analysis due to the risk of bias (ex-, pre- and postoperative PCO, change in PCO; slope and its discrepancy). Two orthopedic surgeons independently measured the pre- and postoperative radiographs, with an interval of 1 week between the measurements. The test–retest method for intra-observer reliability was performed by each surgeon 2 weeks after the first measurement. The inter- and intra-observer reliability was calculated with the intraclass correlation coefficient (ICC) for consistency, which quantifies the proportion of the variance due to the variability. The significance level was set at 0.05. This study was approved by our institutional review board.

Results

Among the 387 knees, 43 (11.1%) showed hyperextension at the last follow-up. However, a severe hyperextension greater than 10° was found only in five knees (1.3%, 5/387 knees). The overall time-dependent mean values of the extension angle are summarized in Table 2. The RM ANOVA analysis revealed statistically significant differences between the groups with time-dependent and time × group (passive vs. gravity) analyses ($p < 0.001$, Greenhouse–Geisser method)

Table 2 Time-dependent mean extension angle between the groups

	Preoperative	Immediate after TKA	POD 3 months	POD 6 months	POD 1 year	POD 3 years	Over POD 5 years	p value[ℙ]
Group 1	9.2° ± 9.8	3.4° ± 3.6	2.9° ± 2.2	2.2° ± 2.8	3.4° ± 3.3	1.9° ± 2.1	2.8° ± 2.1	0.000/0.000
Group 2	10.6° ± 7.2	2.7° ± 3.2	2.3° ± 2.5	− 0.2° ± 3.2	− 7.2° ± 6.1	− 8.4° ± 5.4	− 8.1° ± 3.6	
p value[ℙℙ]	0.365	0.225	0.098	0.000	0.000	0.000	0.000	

[ℙ] p value for RM-ANOVA: time/time × group

[ℙℙ] p value for post hoc analysis

(Fig. 5). In the post hoc analysis, there were no statistical differences in the extension angle until 3 months after the TKA, and a statistical difference was found after 6 months of TKA. A severe hyperextension with an angle greater than 10° was first found after 1 year of TKA. There was no statistical difference between the groups except mechanical with regard to the tibiofemoral angle and the preoperative PCO value. The MAD and the PCO in the hyperextension group (group 2) were found to be larger than those of the non-hyperextension group (group 1) (Table 1).

The final clinical results of both groups are summarized in Table 3. Comparing the results between the groups at the final follow-up, there were no statistically significant differences in the clinical outcomes in the WOMAC total, HSS scores and KS knee score, but the hyperextension angle, WOMAC function scores and KS Function score were significantly worse in group 2. Especially, the KS function on the stairs was found to be significantly worse in group 2, as well as the stair scores in the WOMAC function scores. The extension angle in the radiograph was found to be larger than the goniometer evaluation.

The radiographic measurements are summarized in Table 4. There were no statistically significant differences between the groups except for the change in the PCO, distal femoral resection slope angle (b), and discrepancy of the slope angle ($a+b$). The preoperative PCO in group 2 was found to be larger than that in group 1, but the postoperative PCO was not statistically different, thus resulting in a larger change in the PCO in group 2 postoperatively. There was a significant association between the preoperative PCO and the change in PCO as indicated by Pearson's correlation coefficient analysis ($r=-0.53$, $p=0.000$). These results

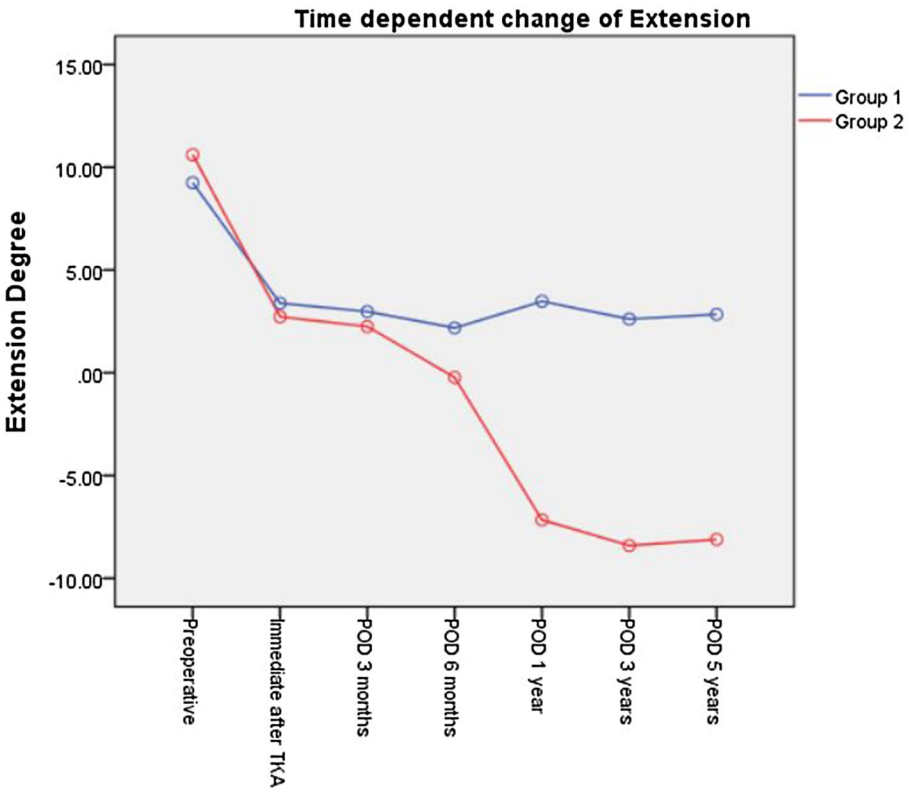

Fig. 5 RM-ANOVA plot for time-dependent extension angle in both groups

Table 3 Comparison of the postoperative clinical outcomes between the groups at the final follow-up (mean ± standard deviation)

	Group 1	Group 2	*p* value
Extension degree (goniometer)	2.8° ± 2.1	− 8.1° ± 3.6	0.000
Extension degree in radiograph	3.4° ± 5.6	− 11.9° ± 3.5	0.000
Flexion	129.6° ± 11.3	129.4° ± 15.8	0.917
HSS score	92.5 ± 9.5	90.3 ± 7.1	0.143
KSS scores			
KS knee Score	91.1 ± 8.6	88.7 ± 10.5	0.094
KS function score—total	86.7 ± 10.1	82.4 ± 9.5	0.008
KS function score—walking	45.8 ± 8.8	45.6 ± 6.2	0.885
KS function score—stairs	42.5 ± 8.4	38.1 ± 8.3	0.001
KS function score—walking aid Used	− 1.3 ± 1.2	− 1.6 ± 2.2	0.169
WOMAC scores			
Total	12.4 ± 5.8	13.4 ± 4.3	0.275
Pain	2.5 ± 2.4	3.0 ± 3.1	0.215
Stiffness	2.0 ± 1.2	1.7 ± 1.1	0.119
Function	7.8 ± 4.3	8.6 ± 5.1	0.261
Pain at going up or down stairs	0.52 ± 0.4	0.8 ± 0.4	0.000
Difficulty with ascending stairs	0.64 ± 1.3	1.1 ± 1.8	0.038
Difficulty with descending stairs	0.65 ± 1.3	1.2 ± 1.5	0.01
Difficulty with rising from sitting	0.43 ± 1.1	0.65 ± 0.9	0.209

Table 4 Comparison of the postoperative radiological outcomes between the groups at the final follow-up (mean ± standard deviation)

	Group 1	Group 2	*p* value
MAD (°)	1.3° ± 2.7	1.9° ± 1.6	0.154
A (°)	88.9° ± 4.6	88.3° ± 3.2	0.407
β (°)	89.5° ± 4.9	90.1° ± 5.6	0.457
γ (°)	3.2° ± 4.0	2.4° ± 3.7	0.213
δ (°)	85.0° ± 3.4	84.3° ± 2.4	0.191
Joint line position (mm)	15.5 ± 3.6	16.6 ± 3.1	0.056
Posterior condylar offset (mm)	26.1 ± 4.0	27.1 ± 3.7	0.12
Tibial posterior slope angle (a)[¶]	8.6° ± 4.6	7.8° ± 5.2	0.29
Distal femoral resection slope angle (b)[¶¶]	− 9.1° ± 2.1	− 12.1° ± 1.7	0.000
Discrepancy of slope angle (a + b)[¶¶¶]	0.3° ± 4.5	− 3.6° ± 3.9	0.000
Change in joint line position (mm)	0.4 ± 4.8	0.6 ± 3.5	0.791
Change in posterior condylar offset (mm)	− 0.2 ± 3.8	− 2.4 ± 3.0	0.003
Change in tibial posterior slope angle	− 4.6° ± 4.8	− 3.7° ± 3.7	0.237

Negative value means valgus limb alignment

MAD, mechanical femorotibial angle

[¶]Positive value: increased slope

[¶¶]Positive value: flexion, negative value: extension position

[¶¶¶]The discrepancy between these angles ($a+b$) was used to determine whether the femoral component position compensated for the tibial component position

indicate that a large preoperative PCO is associated with a greater decrease in PCO. The distal femoral resection slope angle (β) and the discrepancy in the slope angle ($a+b$) in group 2 were found to have a greater extension (as a negative value) than those in group 1.

Pearson's correlation coefficient analysis with the postoperative extension angle is summarized in Table 5. The evaluations of PCO, preoperative MAD and clinical outcomes were correlated with the postoperative extension angle. Among them, the coefficient value of the postoperative KSFS was found to be higher than that of the postoperative KSKS, even though the coefficient value seems to be moderate. The logistic regression analysis is summarized in Table 6. The increase in the preoperative MAD, the decrease

Table 5 Pearson's correlation coefficient was shown between the extension angle and outcome data

Measurements	Postoperative Extension angle	
	r value	*p* value
Postoperative KSKS	0.19*	0.006
Postoperative KSFS	0.393*	0.005
Postoperative WOMAC	− 0.109	0.118
Preoperative MAD (°)	0.224*	0.001
Preoperative PCO (mm)	− 0.293*	0.000
Postoperative PCO (mm)	− 0.191*	0.006
Change in PCO (mm)	0.16*	0.022
Discrepancy of slope angle (°)	0.325*	0.000
Change in joint line position (mm)	− 0.068	0.328
Change in tibial posterior slope angle (°)	− 0.065	0.355

Negative value means valgus limb alignment

MAD, mechanical femorotibial angle

in the change in PCO and the discrepancy in the slope angle were significant factors for the risk for hyperextension after a primary TKA using the LCS design. The linear regression analysis is summarized in Table 7. The change in PCO, discrepancy of the slope angle and preoperative MAD were also determined to be predictive factors for the degree of the postoperative extension. On the other hand, the change in joint line position was significant in the multivariate linear regression analysis, while it was not significant in the logistic regression analysis. In the equation derived using the univariate linear regression analysis for the change in PCO, a 6.1 mm decrease in the postoperative PCO induces a decrease equal to 1° in the flexion contracture, which could be associated with hyperextension (Fig. 6a). Moreover, a 4.9° decrease in the discrepancy of the slope angle, indicating an extended position, could induce a decrease equal to 1° in the flexion contracture (Fig. 6b). However, the adjusted R^2 values were found to be very low in the multivariate and univariate linear regression analysis.

Table 6 The factors associated with a risk of hyperextension are shown

Factor	Odds ratio	*B* value ± SE	95% confidence interval	*p* value	Nagelkerke R^2
Risk of postoperative hyperextension on logistic regression analysis					
Preoperative MAD (°)	1.1	0.091 ± 0.03	1.032–1.163	0.003	0.323
Change in PCO (mm)	0.86	− 0.151 ± 0.06	0.765–0.967	0.012	
Change in joint line position (mm)	1.11	0.104 ± 0.047	1.013–1.216	0.056	
Discrepancy of slope angle (°)	0.813	− 0.208 ± 0.05	0.737–0.895	0.000	
Constant term	–	13.189 ± 5.057	–	0.009	

Negative value means valgus limb alignment

MAD, mechanical femorotibial angle; SE, standard error

Table 7 The predictive factors for the degree of postoperative extension were shown

Factors	*B* value ± SE	*p* value	Adjusted R^2
Multivariate regression analysis to predict the postoperative extension degrees			
Change in PCO (mm)	0.181 ± 0.089	0.044	0.162
Preoperative MAD (°)	0.137 ± 0.05	0.007	
Discrepancy of slope angle (°)	0.331 ± 0.071	0.000	
Change in joint line position (mm)	− 0.165 ± 0.072	0.023	
Constant term	− 22.131 ± 8.501	0.01	
Univariate linear regression analysis to predict the postoperative degree			
Change in PCO (mm)	0.284 ± 0.093	0.003	0.043
Constant term	0.734 ± 0.354	0.039	
Discrepancy of slope angle (°)	0.359 ± 0.073	0.000	0.101
Constant term	0.788 ± 0.341	0.022	
Change in joint line position (mm)	− 0.123 ± 0.077	0.113	0.007
Constant term	0.634 ± 0.358	0.078	

Negative value means valgus limb alignment

MAD, mechanical femorotibial angle; SE standard error

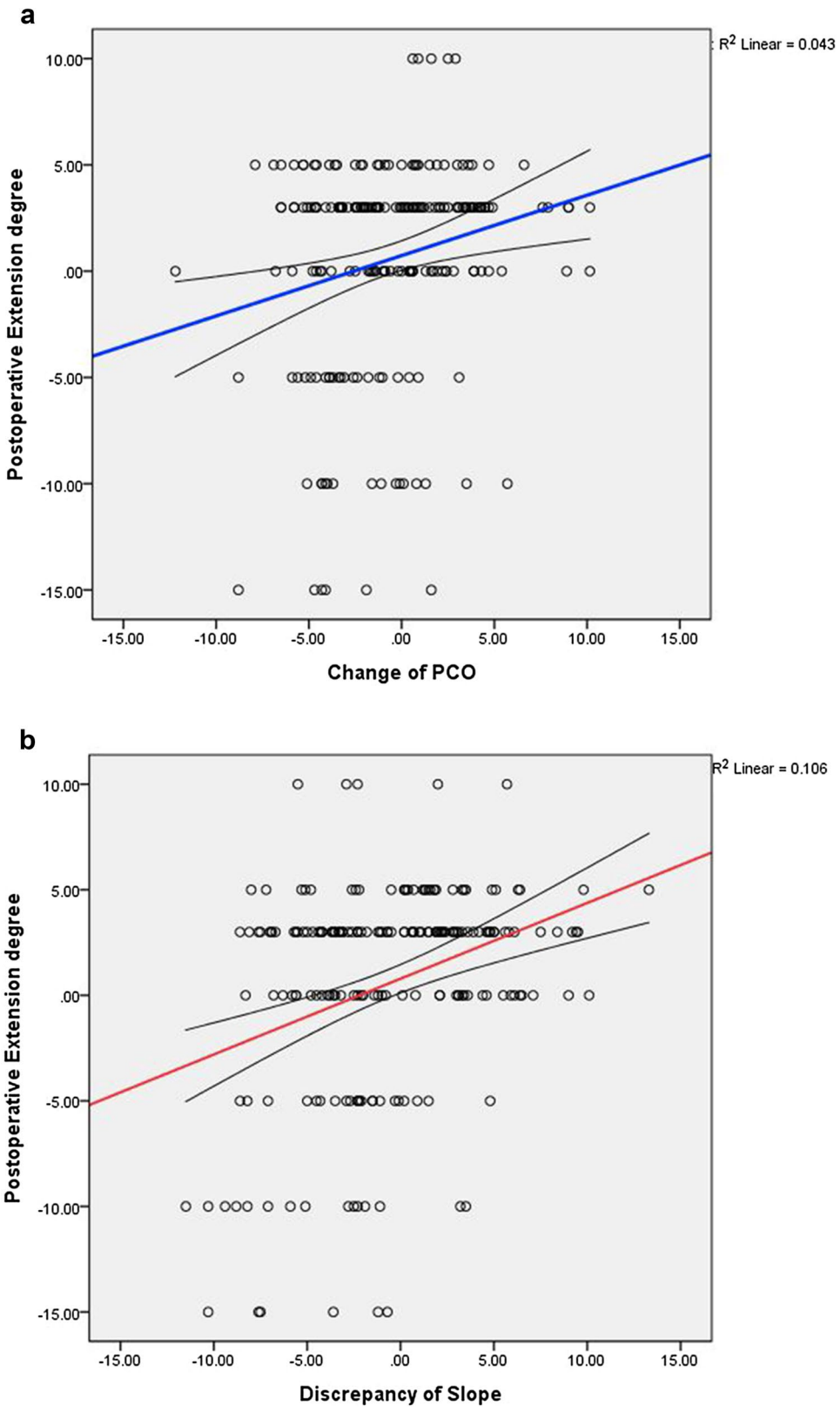

Fig. 6 **a** Overall correlation of the changing value of posterior condylar offset distance and extension angle after TKA. **b** The overall correlation of the changing degree of discrepancy of the slope angle ($\alpha+\beta$) and the extension angle after TKA. The fit line from the equation obtained in the univariate regression analysis and its 95% confident interval are shown

No complications such as infection, early aseptic loosening of the component, patellar maltracking, mediolateral instability and radiolucent lines were encountered in this series.

The overall ICC of the radiologic measurements were greater than 0.83 (range 0.83–0.92), indicating that all measurements had good inter- and intra-observer reliability.

Discussion

The purpose of this study was to investigate the incidence and factors associated with postoperative hyperextension. We found that 11.1% of the knees showing a hyperextension greater than 5° after the 5-year follow-up presented a worse functional outcome, especially with stairs, even though no serious complications were noted. Moreover, the factors associated with postoperative hyperextension were increased preoperative MAD, decreased change in the PCO, and discrepancy of the slope angle. Based on the equation of the univariate analysis, a 6.1 mm decrease in the PCO and a 4.9° decrease in discrepancy of the slope angle seemed to induce a hyperextension of 1°.

Hyperextension after TKA has been known to be a complication that should be avoided during surgery because of the its associated functional deficits [10]. However, only a few studies have focused on the role of knee extension after TKA associated with rare conditions including autoimmune diseases and previous surgeries [11, 12, 27–29]. Thus, the incidence of hyperextension and its role or acceptable range after a primary TKA has not been well documented [13, 26]. In a study by Siddiqui et al. [13], the incidence of postoperative hyperextension greater than 5° was found to be 8.2% in 2587 conventional TKAs. However, 27.6% of cases presented extensions greater than 0°. They reported that patients with hyperextensions at 6 months are 6.5 times more likely to present hyperextensions after 2 years, and a mediolateral laxity of more than 5 mm could be a risk factor for hyperextension. Additionally, the functional outcomes were worsened with an increased hyperextension deformity of more than 5°. In the study by Kim et al. [26], 3.2% of patients (7/215) had hyperextensions over 5° at the final follow-up, but the incidence of a residual hyperextension between 0° and 5° was 12.6% (27/215). In a study by Ritter et al. [11], a 1.6% incidence of hyperextension was found in 5622 conventional TKAs.

However, in our study, the incidence of residual hyperextensions greater than 5° was 11.1% at the final follow-up, which is somewhat more frequent than the 8.2% indicated by Siddiqui et al. [13] Moreover, the hyperextension started to worsen after 6 months of TKA which was not shown just after the surgery, and remained as hyperextension after 1 year of TKA. The patients might achieve full recovery and soft tissue stabilization without any pain or swelling after 6 months of surgery, the hyperextension would be found after this period. Moreover, because the mobile-bearing prosthesis of the LCS design concept was used for this study, the higher incidence of hyperextension in this study could be derived from a combination of multiple factors including the design of the prosthesis, soft tissue balancing due to severe varus, decreased PCO and resection angle mismatch. The distal femoral resection of the LCS system was angled at a 10° extension to the long anatomic axis of the femur, to match the 7°–10° of inclination resection angle of the proximal tibia. The hyperextension could be shown more frequently than in other prostheses wherein resection was usually performed vertically to the axes of the femur (Fig. 7). In this study, the discrepancy in the slope angle ($a+b$) was assessed to address this design feature. If the resection angle is not appropriately matched in the femur and tibia, there may be possible increased risks of hyperextension in the LCS design, because the anterior lip of the deep dish bearing might be insufficient to prevent hyperextension, along with the absence of cam-post design, when the resection angle was not matched.

According to the results of this study, the decreased discrepancy in the slope angle (negative value), which means that the combined prosthesis position was hyperextension,

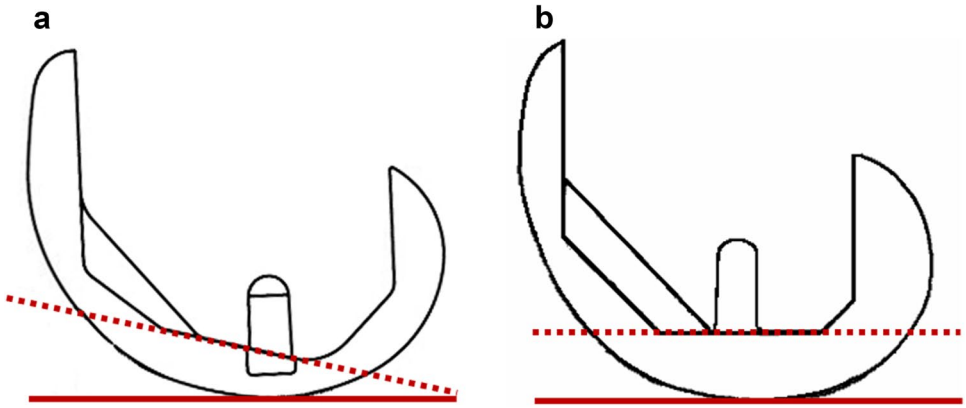

Fig. 7 The difference in the distal femur resection angle between the LCS mobile-bearing system and other conventional prosthesis is shown. A reference line here was drawn as vertical to the long anatomical axis of the femur. **a** LCS mobile system set at 10° to the reference line. **b** Conventional TKA parallel to the reference line

was the factor for the hyperextension in this study. Using the equation, a 4.9° decrease in the discrepancy of the slope angle seemed to induce 1° of hyperextension, although the adjusted R^2 value seems relatively low (Table 7, Fig. 6b). Due to the large decrease value of the discrepancy of the slope angle (4.9°) would be needed to affect 1° of the hyperextension angle, the clinical safe range for the discrepancy of the slope angle may be sufficiently wide, but combined with other factors, it could worsen the hyperextension after LCS-TKA. Interestingly, a preoperative genu recurvatum was found in six patients (more than 5° of hyperextension), the deformity of all these patients was corrected using neutral extension angle until the final evaluation. Therefore they were categorized as group 1 at the final follow-up. Further studies are needed with more various demographic data.

On the other hand, a decreased value of the condylar offset of the posterior femoral condyle compared with the preoperative value was found as a factor for hyperextension of mobile bearing of the LCS system in this study. Mitsuyasu et al. [30] found that an enlarged posterior femoral component reduces the extension gap, resulting in a reduction in the extension gap due to posterior tissue tightness. In the study of Kim et al. [26], the changed value of the PCO could affect the posterior capsular tightness when using the fixed bearing TKA, and they found that it could be associated with a decreased hyperextension during follow-up due to the healing potential of posterior capsule after release. In this study, the change in PCO was also positively correlated with postoperative extension degrees (Table 5), negatively correlated with preoperative PCO ($r = -0.53$), and found as a risk factor for hyperextension when using the mobile-bearing LCS system (Tables 6, 7, Fig. 5a). However, unlike the study of Kim et al. [26], the hyperextension degree was not decreased during follow-up. The change in PCO would obviously affect the posterior capsular laxity [26, 30–34], but it could affect the mobile-bearing LCS system combined with the unique angle of the distal femoral cut to a greater degree. In addition, a preoperative varus angle was also found to be a risk factor in this study and a more aggressive release of the medial compartment decrease of PCO could induce a postoperative hyperextension, especially in patients with large preoperative PCO with LCS mobile-bearing design. However, like the discrepancy in the slope angle, a wide clinical safety range was found for the change in PCO (6.1 mm); evaluation of other factors that were not included in this study would be needed for postoperative hyperextension. In brief, surgeons should be careful to match the slope angles in the femur and tibia and not to lose extensively in the PCO when resection was performed along with soft tissue balancing. Further study would be needed to specify the risk factors according to the design.

The functional outcomes of the stairs were found to be worse in the hyperextension group, as shown by previous studies [13, 26]. However, the definition and measurement of hyperextension were different in the various studies thus the incidence and outcomes of hyperextension after TKA were hard to compare in the same line. There were measurement errors from the goniometer for hyperextension [35, 36], and the definition of hyperextension was still not conclusive; thus, the clinical outcomes between the real hyperextension and measured hyperextension may have been mixed up. In our study, the hyperextension angles between the goniometer and radiograph were also statistically different; thus, the results could be changed if the radiograph were used to define the hyperextension ($p = 0.000$) (Table 3). Nevertheless, the functional scores in the hyperextension group were found to be worse, especially in the stairs. Since hyperextension may negatively affect the stability of the knee joint and quadriceps or hamstring fatigue during ascending and descending stairs, the functional scores in stairs might be worse than that of the flat floors. (Table 3) Thus, severe hyperextension should be avoided during mobile-bearing total knee arthroplasty. Moreover, it is necessary to define the hyperextension angle more specifically in further studies.

There were some limitations to this study. First, the accuracy of the measurements was controversial. The goniometer is a well-known measurement tool for evaluation ROM, but also known to have error around 5° [20, 21, 36]. Thus, the clinical results associated with hyperextension in the various studies may have been different due to measurement errors. This could also be a reason for the relatively high incidence of hyperextension in this study. Further studies are needed to specify the definition of hyperextension using more reliable measurements. Second, the number of hyperextension cases was relatively small, although the prevalence of hyperextension in this study was higher than previous studies. Moreover, this is a retrospective study and the risk factors of this study need to be verified in a prospective fashion. However, there are only few studies investigating hyperextension in mobile-bearing prostheses. Therefore, it may be of value to show the results of the mid-term follow-up. Third, different results may have been obtained with another type of prosthesis other than the LCS design. Since the surgical and prosthesis concepts of would be different in another prosthesis, the clinical outcomes could be different with the same angle of hyperextension when using other prosthesis. Fourth, the mediolateral gap was not evaluated by the objective measurements, such as stress radiography, which would be a factor for postoperative hyperextension [13, 37]. However, there was no case of severe mediolateral imbalance during manual examination at the follow-up period. Fifth, to find the factors that affect the hyperextension, further studies with long-term periods are needed with more information about demographics. Although the decreased PCO and the discrepancy in the slope angle were found to be risk factors for hyperextension, the statistical power was low. Several

factors including the design of the prosthesis, mediolateral gap, flexion–extension gap, weakness of quadriceps, etc., could affect the development of hyperextension after TKA. Comparison of the hyperextension results with other prosthesis would be helpful to evaluate the factors for hyperextension. However, several significant factors in this study also affect hyperextension and care should be taken during operation and evaluation.

In brief, hyperextension after TKA with an LCS mobile-bearing design could be followed if the resection angle of the femur and tibia do not match or if a decreased PCO with preoperative severe varus is found. However, the remaining hyperextension was not progress over years, and the clinical outcomes were acceptable but the functional outcomes were worse in the hyperextension group, especially in the stairs. Careful media-lateral balancing including a possible change in PCO and assessing resection angle discrepancy in femur and tibia should be addressed during TKA with an LCS design.

Conclusion

Mobile-bearing TKA with hyperextensions greater than 5° showed worse functional outcomes at the mid-term follow-up, even though no serious complications exist. Care should be taken to maintain the PCO and to match the resection angles in the femur and tibia due to the risk of hyperextension and the worse functional outcomes.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval The study was approved by the Institutional Review Boards of Chung-Ang University Hospital (no.: 1702-006-16037) and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

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