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Risk factors of de novo hyperextension developed after posterior cruciate ligament substituting total knee arthroplasty:
a matched case-control study

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이 논문을 의학석사 학위논문으로 제출함

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ABSTRACT

Risk factors of de novo hyperextension developed after posterior cruciate ligament substituting total knee arthroplasty: a matched case-control study

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Introduction: Hyperextension is one of the complications that can occur after total knee arthroplasty (TKA), and it can be difficult to manage. Although many studies have focused on hyperextension developing in the immediate post-operative period, there is only limited research on its occurrence during follow-up after TKA. The purpose of this study was to investigate factors contributing to the de novo development of hyperextension after posterior cruciate ligament substituting (PS) TKA.

Materials and Methods: Through a retrospective case-control study, de novo hyperextension patients were compared with patients without hyperextension after primary PS TKA. Eighty-five de novo hyperextension patients were compared with 85 patients in a control group matched by age, sex, surgeon and implant. The clinical and radiographic parameters, including the mechanical axis (MA), joint line convergence angle (JLCA), posterior tibial slope angle (PTSA), posterior condylar offset (PCO), and the gamma angle were evaluated preoperatively and immediate postoperatively. Comparisons between the two groups and logistic regression analysis were performed to investigate factors contributing to the development of de novo hyperextension after PS TKA.

Results: Among the clinical factors, preoperative flexion contractures were less (5.2° ± 5.7° vs. 10.5° ± 6.1°, $p < 0.001$) and the range of motion was greater (124.7° ± 11.5° vs. 117.6° ± 5.4°, $p = 0.041$) in the de novo hyperextension group than in the control group. Among the radiographic parameters, preoperative and postoperative JLCA were greater (8.1° ± 4.4° vs. 6.1° ± 3.5°, $p = 0.002$, 1.0° ± 1.3° vs. 0.2° ± 0.8°, $p < 0.001$, respectively), postoperative PTSA was greater (3.7° ± 2.0° vs. 3.3° ± 1.6°, $p < 0.001$) and preoperative and postoperative PCO were less in the hyperextension group than in the control group (26.3 mm ± 3.3mm vs. 29.1 mm ± 3.2mm, $p < 0.001$, 26.4 mm ± 3.2mm vs. 29.1 mm ± 3.0mm, $p < 0.001$, respectively). In multivariate analysis, the degree of medial soft tissue release [odds ratio (OR) 2.25, $p= 0.001$], mechanical axis change after surgery [OR 2.28, $p < 0.001$], preoperative JLCA [OR 1.14, $p = 0.002$], and preoperative and postoperative PCO [OR 0.79, $p < 0.001$, OR 0.79, $p < 0.001$, respectively] were the factors associated with the development of de novo hyperextension after PS TKA.

Conclusion: An increased degree of medial soft tissue release, pre- and postoperative JLCA, a change in the mechanical axis and a decreased pre- and postoperative PCO were risk factors of de novo hypertension. To avoid de novo hyperextension after posterior stabilized type TKA, careful soft tissue balancing should be undertaken in patients with these risk factors who have a large range of motion despite advanced osteoarthritis. In addition, residual medial-lateral laxity measured by postoperative JLCA in supine X-ray can predict the development of hyperextension after TKA in these patients.

Keywords: De novo hyperextension, recurvatum, PCL substituting, total knee arthroplasty

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INTRODUCTION

Tibiofemoral instability is becoming a more frequent complication of primary and revision total knee arthroplasty (TKA), affecting up to 22% of all knee arthroplasties. (1-3) It is one of the most common early complications, with a rate up to 26% during the first 5 years after surgery, and it is the second most common cause of revision after periprosthetic infection. (3-5) Many factors contribute to the development of tibiofemoral instability, such as ligament imbalance, ligament insufficiency, component malposition, connective tissue disease, or an insufficient extensor mechanism. (4, 6) Hyperextension has been observed to occur mainly in patients with preoperative recurvatum, a fixed valgus deformity or neuromuscular problems. (7)

Hyperextension after TKA has been reported to result in poor patient satisfaction after surgery. If hyperextension occurs after surgery, the patient continues to push the knee into hyperextension to help stabilize the limb during the stance phase of the gait cycle, in which results in quadriceps femoris muscle exhaustion. (8) According to recent studies, the ability to climb stairs was found to be worse if there is more than 10° of hyperextension. (9, 10) Once hyperextension after TKA occurs, it is hard to manage. Therefore, the prevention of postoperative hyperextension after TKA is considered to be the best option. (11)

Due to the rarity of the hyperextension after TKA, there is still insufficient research and consensus on the definitions, incidence and timing of its occurrence. (8, 10) In some cases, hyperextension occurs immediately after TKA, but there are a few cases where hyperextension progresses gradually after a period of time, even though no unusual findings are shown immediately after surgery, and research on this late complication is very limited. I defined this gradual development of hyperextension after TKA as 'de novo hyperextension'.

Therefore, I aimed to investigate the incidence and the factors associated with postoperative de novo hyperextension found during follow-up after posterior cruciate ligament substituting (PS) TKA. I hypothesized that patients with hyperextension had different clinical and radiological features before TKA as well as immediate postoperatively compared with patients without hyperextension.

MATERIALS AND METHODS

From December 1999 to December 2017, 3864 primary PS TKAs were performed at a single tertiary referral hospital by 3 senior surgeons. This is a single institution retrospective matched case−control study and it was approved by the Institutional Review Board of Seoul National University Hospital (IRB No. H − 2009 − 051 − 1155).

The patients were divided into two groups. An extension greater than 5° measured using a goniometer at the postoperative follow−up was defined as hyperextension. The number of patients in the hyperextension group was 96 out of 3864 knees (2.4%), while 3768 out of 3864 (97.6%) knees showed no evidence of hyperextension. The inclusion criteria for the hyperextension group were patients (1) who newly developed hyperextension ≥5° during follow−up when checking passive extension in the supine position with a goniometer, and (2) with a follow−up of more than 2 years. The exclusion criteria were as follows: (1) preoperative or immediate postoperative hyperextension within the first 3 months after surgery, (2) operative history (other than the TKA) on the affected limb, (3) the presence of clinical general laxity, (4) lower extremity weakness due to a neuromuscular comorbidity, (5) a lack of informative data, (6) revision cases with a major postoperative event including infection, aseptic loosening or periprosthetic fracture (Fig. 1). After the exclusion criteria were applied, a total of 76 patients (85 knees) were eligible for this study as the case group.

After applying the same inclusion and exclusion criteria (except for the development of hyperextension), propensity matching was performed to obtain a matched control group (1:1, nearest neighbor matching without replacement). Matching variables included age at surgery, sex, surgeon and implant. The absolute value of the standardized mean difference of each matching variable was <0.1. Finally, 85 controls were enrolled (Fig. 1).

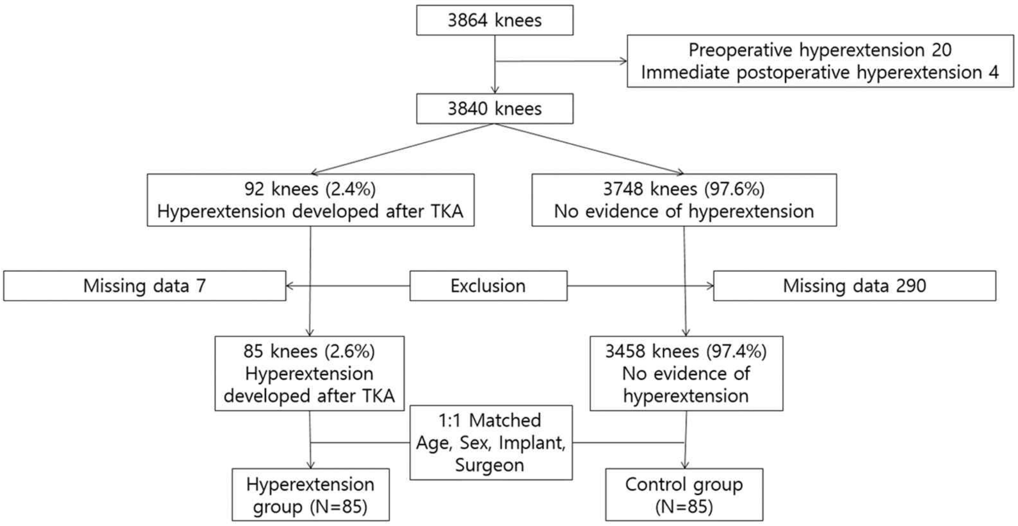

Figure 1. Flow diagram of patients screened and grouped.

TKA = total knee arthroplasty

Surgical technique

The primary TKAs were performed using a conventional technique with a tourniquet applied. After a standard medial parapatellar approach was employed in all procedures, the anterior and posterior cruciate ligaments were excised in all patients in both groups. The valgus resection of the distal femoral condyle was conducted according to the valgus angle of the distal femur, which was measured on preoperative weight-bearing antero-posterior teleradiography. Tibial cutting was conducted using an extramedullary guide and a jig aligned perpendicular to the anatomical axis of the tibia coronally. The size of the femoral component and the rotational alignment was determined using both the ligament tension and the anatomical epicondylar axis. Adequate soft tissue balancing was achieved by medial soft tissue release depending on the severity of the medial soft tissue contracture; deep medial collateral ligament, superficial medial collateral ligament or semimembranous muscle, posteromedial capsulotomy, other pes anserius muscle or medial collateral ligament pie crust, and confirmed by symmetrical leg distraction using serial gap spacers. Even though the soft tissue balancing and bone resection was complete, an additional distal femoral resection was performed to eliminate residual flexion contracture. A sequential posterior capsular release was performed when the patients without pre-operative hyperextension had flexion contractures 5° despite removal of the posterior osteophytes: first, capsular release around the intercondylar notch, then subperiosteal elevation of the capsule from the posterior femoral condyles if needed. (12) All components were fixed with bone cement.

Clinical Evaluation

The patients were evaluated preoperatively and postoperatively at 1 month, 3 months, 6 months, and 1 year and annually thereafter. The passive ROM was measured to the nearest 5° using a goniometer with the patient in a supine position by experienced research assistants. Postoperative complications were also evaluated during the follow-up period. The degree of medial soft tissue release is defined by the ligament complex structure released intraoperatively. Releasing the deep medial collateral ligament is defined as grade 1, the superficial medial collateral ligament or semimembranous muscle as grade 2, posteromedial capsulotomy, other pes anserius muscle or medial collateral ligament pie crust as grade 3, and this grade was recognized as an independent factor in the statistical analysis.

Radiographic Evaluation

Full length and standing anteroposterior, lateral, and skyline view images were acquired at each follow−up visit. The standing patient was positioned with both feet in a symmetric internal rotation to bring both patellae into a forward−facing position. The mechanical tibiofemoral angle (measured as the Hip − Knee − Ankle angle) was measured preoperatively, immediate−postoperatively, at the time when hyperextension developed and at the final follow−up in the outpatient clinic. The joint line convergence angle (JLCA) was measured in the preoperative standing anterior−posterior (AP) view and the immediate postoperative supine AP view to assess the medio−lateral ligament balance (Fig. 2). The tibial posterior slope angle was defined as the angle between the medial tibial plateau line (preoperatively) or the undersurface of the tibial component (postoperatively, the same value as the delta angle) and the line connecting the center of the medullary canal on a supine lateral knee radiograph. The posterior condylar offset (PCO) and the PCO ratio (PCOR) were measured as the distance from the femoral posterior cortex to the condyle posterior cortex and its proportion to the whole condyle anteroposterior length in the supine lateral view was evaluated pre− and postoperatively.

The radiologic parameters were measured twice by two orthopedic surgeons at a one−week interval. Measurements of radiologic parameters were performed using Picture Archiving Communication System software (PACS; Infinitt, Seoul, Korea) with a minimal detectable angular change of 0.1°. The intra−class correlation coefficient (ICC) was used for the test− test reliability of the radiologic parameter measurements.

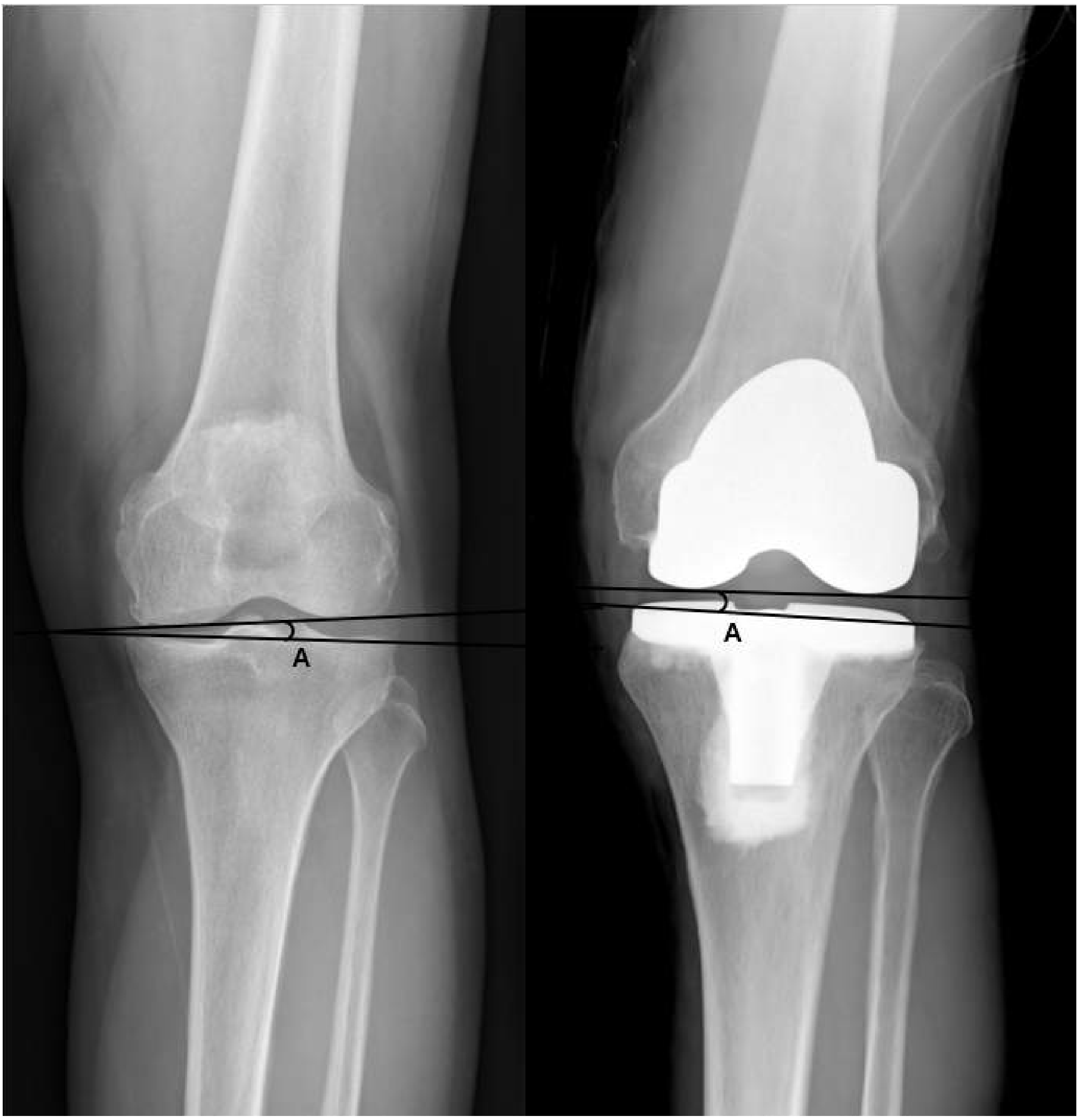

Figure 2. Radiographic parameter measurements of the pre– and postoperative joint line convergence angles (JLCAs).

Statistical Analysis

All variables are described with the mean value and standard deviation. A paired t−test, Pearson's chi−square test and Fisher's exact test were performed to compare the clinical factors and radiographic parameters between the hyperextension and control group. Binary logistic regression was used to assess the risk of de novo hyperextension compared to the control group and de novo hyperextension greater than 5° as compared to 5° hyperextension. All variables for the logistic analysis were described with the odds ratio and 95% confidence interval. For highly associated factors such as preoperative PCO and postoperative PCO, excluding the same diaphyseal diameter, separate logistic regression analyses were conducted as an individual model. Variance inflation factor (VIF) was used to test for multicollinearity between all independent variables before including them in the final models. VIF of independent variables over multivariate regression analysis were below 10 and the collinearity among variables were not significant. 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. Statistical analyses were conducted using SPSS for Windows version 19.0 (SPSS, Chicago, IL, USA). The significance level was set at 0.05.

RESULTS

At the time of the TKA surgery, the average age of the patients was 67.9 ± 6.5 years(range 53– 83 years). The patient demographics of the de novo hyperextension and control group are summarized in Table 1. The mean follow-up was 75.2 ± 31.6 months in the de novo hyperextension group and 63.3 ± 11.5 months in the control group. Mean duration to the development of de novo hyperextension was 3.6 ± 2.4 years.

There was no significant difference between the two groups except for the preoperative flexion contracture and the preoperative range of motion (ROM) (Table 1). Mean preoperative flexion contracture and further flexion were, respectively, 5.2° ± 5.7° and 130.7° ± 9.9° in the hyperextension group and 10.5° ± 6.1° and 128.2° ± 11.6° in the control group ($p < 0.001$, $p > 0.05$, respectively). Mean preoperative ROM was 124.7° ± 11.5° in the hyperextension group and 117.6° ± 5.4° in the control group ($p=0.041$). Postoperative ROMs of the two groups were not significantly different.

Table 1. Baseline characteristics of de novo hyperextension group and control group.

Characteristics	Hyperextension group	Control group	*p*
Age of surgery* (years)	67.9 ± 6.5	68 ± 6.3	n.s [a]
Sex (Male : Female)	9 : 76	8 : 75	n.s[b]
Side (Right : Left)	39 : 46	47 : 38	n.s[b]
Height* (cm)	152.1 ± 6.5	152.7 ± 6.2	n.s [a]
Weight* (kg)	61.5 ± 8.5	62.1 ± 9.9	n.s [a]
Body mass index* (kg/m^2)	26.6 ± 3.4	26.7 ± 4.6	n.s [a]
Preoperative flexion contracture* (°)	5.2 ± 5.7	10.5 ± 6.1	<0.001
			[a]
Preoperative further flexion* (°)	130.7 ± 9.9	128.2 ± 11.6	n.s [a]
Pre ROM* (°)	124.6 ± 11.5	117.6 ± 5.4	<0.001
Postoperative flexion contracture* (°)	0.6 ± 1.8	0.6 ± 2.6	[a]
Postoperative further flexion* (°)	132.2 ± 7.9	131.2 ± 8.5	n.s [a]
Post ROM* (°)	128.6 ± 9.6	128.4 ± 8.6	n.s [a]
Duration of hyperextension	3.6 ± 2.4		n.s [a]
development* (years)			n.s [a]
Medial soft tissue release			
Grade I	40 (47.1%)	29 (38.1%)	n.s[b]
Grade II	38 (44.7%)	20 (23.5%)	
Grade III	3 (3.5%)	3 (3.5%)	

Pre ROM = Preoperative range of motion; Post ROM = Postoperative range of motion

*Values are expressed as the mean ± standard deviation or number (percentage).

[a] Paired t−test; [b]Fisher's exact test

In the description of the radiologic parameters, I excluded two models of implants in the comparison of PTSA because they had a high default setting angle of the tibial tray (LPS flex; The NexGen® LPS-Flex, Zimmerbiomet, Warsaw, IN, USA, setting at 7°, LCS; LCS®, DePuy Orthopaedics, Inc, Warsaw, IN, USA, setting at 5°). The comparison between these two models showed no significant difference between two groups (Table 2.). The ICC for intra-observer reliability was 0.85- 0.95 for all measurements and the inter-observer reliability was 0.63- 0.84.

Mean preoperative mechanical axis measured by the HKA angle was 12.2° ± 6.8° in the hyperextension group and 11.1° ± 5.2° in the control group, which were not significantly different. The postoperative HKA angles were not different between the two groups either (0.84° ± 2.8° vs. 0.60° ± 2.2°). The HKA angle measured at the time of de novo hyperextension development and final follow-up showed no significant fluctuation after de novo hyperextension development (Fig. 3).

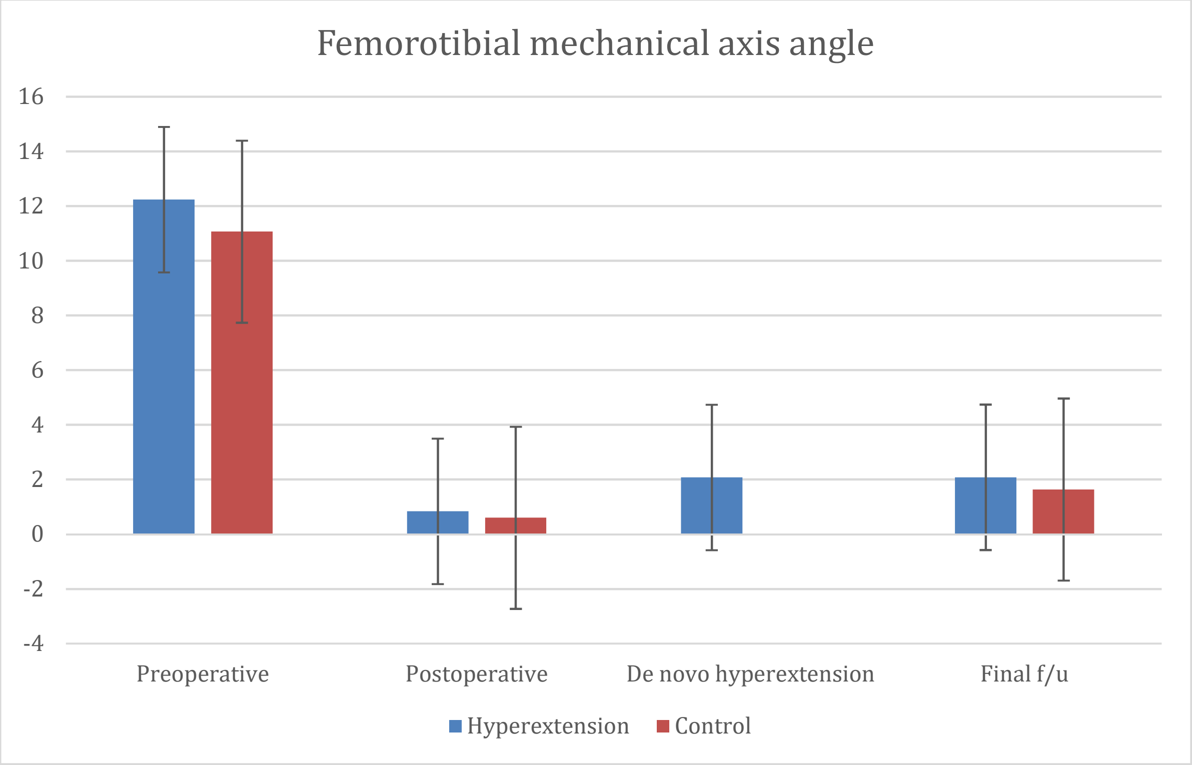

Figure 3. Mean value of the femorotibial mechanical axis angle measured by the Hip – Knee – Ankle (HKA) angle during the preoperative period, the postoperative period, after de novo hyperextension development and at the final follow up (f/u) in the de novo hyperextension group. In the control group, the HKA angles at the same times (except after de novo hyperextension development) were measured. Mean HKA angles are shown as a bar with standard deviation.

Mean preoperative JLCA was 8.1° ± 4.4° in the hyperextension group and 6.1° ± 3.5° in the control group (p = 0.002), and the postoperative JLCA was 1.0° ± 1.3° in the hyperextension group and 0.2° ± 0.8° in the control group (p < 0.001), both significantly different. Mean preoperative PCO was 26.3 mm ± 3.3mm in the hyperextension group and 29.1 mm ± 3.2mm in the control group (p < 0.001). Mean postoperative PCO was 26.4 mm ± 3.2mm in the hyperextension group and 29.1 mm ± 3.0mm in the control group (p < 0.001). However, PCOR was not different between the groups both preoperatively and postoperatively. Mean postoperative PTSA was 3.7° ± 2.0° and 3.3° ± 1.6° in the control group (p < 0.001), whereas the mean preoperative PTSA showed no significant difference.

Table 2. Comparison of radiographic parameters between the de novo hyperextension group and the control group.

Parameters	Hyperextension group	Control group	*p*
Pre MA (°)	12.2 ± 6.8	11.1 ± 5.2	n.s
Post MA (°)	0.84 ± 2.8	0.60 ± 2.2	n.s
MA gap (°)	11.4 ± 7.1	10.5 ± 5.0	n.s
Final MA (°)	2.1 ± 3.7	1.6 ± 2.3	n.s
Pre JLCA (°)	8.1 ± 4.4	6.1 ± 3.5	**0.002**
Post JLCA (°)	1.0 ± 1.3	0.2 ± 0.8	**<0.001**
Pre PTSA (°)	10.4 ± 4.9	9.4 ± 4.5	n.s
Post PTSA (°)	3.7 ± 2.0	3.3 ± 1.6	**<0.001**
Pre PCO (mm)	26.3 ± 3.3	29.1 ± 3.2	**<0.001**
Pre PCOR	0.51 ± 0.1	0.51 ± 0.1	n.s
Post PCO (mm)	26.4 ± 3.2	29.1 ± 3.0	**<0.001**
Post PCOR	0.50 ± 0.1	0.51 ± 0.1	n.s
γ angle (°)	4.7 ± 2.7	4.8 ± 2.1	n.s

Values are expressed as the mean ± standard deviation or number (percentage).

Pre MA = Preoperative mechanical axis; Post MA = Postoperative mechanical axis; MA gap = Difference of mechanical axis measured pre and postoperatively; Hyper MA = Mechanical axis measured at hyperextension development; Final MA = Mechanical axis measured at final outpatient clinic follow up; Pre JLCA = Preoperative joint line convergence angle; Post JLCA = Postoperative joint line convergence angle; Pre PTSA = Preoperative joint line convergence angle; Post PTSA = Postoperative joint line convergence angle

Boldface indicates statistical significance.

The binary logistic regression analysis is summarized in Table 3. In the univariate analysis, an increased degree of medial soft tissue release (medial release) (OR 2.25 [95% CI 1.37 to 3.70]; p = 0.001), a low profile of preoperative flexion contracture (FC) (OR 0.88 [95% CI 0.83 to 0.93]; p < 0.001), a wide preoperative range of motion (ROM) (OR 1.04 [95% CI 1.02 to 1.07]; p = 0.002), an increased value of pre- and postoperative JLCA (OR 1.14 [95% CI 1.05 to 1.24]; p = 0.002, OR 3.27 [95% CI 1.88 to 5.70]; p < 0.001, respectively), the discrepancy in the mechianical axis pre-and postoperatively (MA gap) (OR 2.28 [95% CI 1.72 to 3.03]; p < 0.001) and pre- and postoperative PCO (OR 0.79 [95% CI 0.71 to 0.87]; p < 0.001, OR 0.79 [95% CI 0.71 to 0.87]; p < 0.001, respectively) were significant factors for the risk of de novo hyperextension. Because preoperative and postoperative PCO might have collinearity caused by sharing the same diaphyseal diameter, I conducted multivariate analyses of preoperative PCO and postoperative PCO seperatively.

According to the multivariate analysis including preoperative PCO, the increased degree of medial release (OR 9.46 [95% CI 1.56 to 58.60]; p = 0.016), MA gap (OR 2.28 [95% CI 1.77 to 4.23]; p < 0.001), the increased value of pre- and postoperative JLCA (OR 1.58 [95% CI 1.11 to 1.24]; p = 0.023, OR 3.50 [95% CI 1.15 to 10.64]; p = 0.039, respectively) and preoperative PCO (OR 0.77 [95% CI 0.60 to 0.98]; p = 0.035) showed significant values associated with the development of de novo hyperextension. On the other hand, an increased degree of medial release (OR 9.61 [95% CI 1.57 to 58.67]; p = 0.014), MA gap (OR 2.28 [95% CI 1.78 to 4.23]; p < 0.001), an increased value of preoperative JLCA (OR 1.57 [95% CI 1.06 to 2.31]; p = 0.023) and a decreased postoperative PCO (OR 0.70 [95% CI 0.52 to 0.93]; p = 0.014) showed significant values associated with the development of de novo hyperextension according to the multivariate analysis, including postoperative PCO.

I conducted a binary logistic regression analysis by dividing the de novo hyperextension group into the development of severe hyperextension (more than 5°) and mild hyperextension (the same or less than 5°) groups to investigate these subgroups. However, no clinical factors nor radiologic parameters showed significant associations with the degree of hyperextension.

Table 3. Univariate and multivariate analyses for factors associated with the development of de novo hyperextension.

Variable	Univariate			Multivariate model 1			Multivariate model 2		
	OR	95% CI	*p*	OR	95% CI	*p*	OR	95% CI	*p*
Sex (Male : Female)	2.25	1.37–3.70	0.1						
Side (Right : Left)	1.50	0.80–2.67	0.22						
Height (cm)	1.02	0.97–1.06	0.49						
Weight (kg)	0.99	0.96–1.03	0.72						
Medial release (grade)	2.25	1.37–3.70	**0.001**	9.46	1.53–58.60	**0.016**	9.61	1.57–58.67	**0.014**
Flexion contracture (°)	0.88	0.83–0.93	**<0.001**	0.98	0.84–1.14	0.54	0.95	0.81–1.12	0.56
Further flexion (°)	1.02	0.99–1.05	0.13						
ROM (°)	1.04	1.02–1.07	**0.002**	1.03	0.95–1.11	0.52	1.03	0.95–1.12	0.51
Pre MA (°)	1.03	0.98–1.09	0.21						
Post MA (°)	1.04	0.92–1.17	0.53						
MA gap (°)	2.28	1.72–3.03	**<0.001**	2.74	1.77–4.23	**<0.001**	2.74	1.78–4.23	**<0.001**
Final MA (°)	1.05	0.95–1.16	0.37						
Pre JLCA (°)	1.14	1.05–1.24	**0.002**	1.58	1.11–2.23	**0.023**	1.57	1.06–2.31	**0.023**
Post JLCA (°)	3.27	1.88–5.70	**<0.001**	3.50	1.15–10.64	**0.039**	3.12	0.935–10.43	0.064
Pre PTSA (°)	1.05	0.98–1.12	0.15						
Post PTSA (°)	1.12	0.95–1.33	0.18						
Pre PCO (mm)	0.79	0.71–0.87	**<0.001**	0.77	0.60–0.98	**0.035**			
Pre PCOR	1.60	0.00–3148.58	0.63						
Post PCO (mm)	0.79	0.71–0.87	**<0.001**				0.70	0.52–0.93	**0.014**
Post PCOR	0.03	0.00–33.97	0.32						
γ angle (°)	0.98	0.87–1.11	0.77						

Pre MA = Preoperative mechanical axis; Post MA = Postoperative mechanical axis;

MA gap = Difference of mechanical axis measured pre and postoperatively;

Hyper MA = Mechanical axis measured at hyperextension development;

Final MA = Mechanical axis measured at final outpatient clinic follow up;

Pre JLCA = Preoperative joint line convergence angle;

Post JLCA = Postoperative joint line convergence angle;

Pre PTSA = Preoperative joint line convergence angle;

Post PTSA = Postoperative joint line convergence angle

Multivariate model1 includes pre PCO and Multivariate model2 includes post PCO.

Boldface indicates statistical significance.

DISCUSSION

The most important findings of the present study were that an increased degree of medial soft tissue release, pre- and postoperative JLCA, changes in the mechanical axis, and a decreased pre- and postoperative PCO can all contribute to the development of de novo hyperextension in patients who have a good range of motion despite the advanced osteoarthritic changes. I also found that increased pre- and postoperative JLCA, a decreased pre- and postoperative PCO, and an increased postoperative posterior tibial slope were significant different in the hyperextension group as well. Furthermore, a preoperative large range of motion and small flexion contracture were notable in the de novo hyperextension group.

Sagittal radiographic parameters

There are several previous studies describing an assocition of PCO with posterior capsule laxity but few researchers have investigated its association with postoperative extension to the best of my knowledge. (6, 9, 13, 14) In the study of Kim et al. (9), postoperative extension degree showed an association with increased preoperative PCO, which is in line with the prese study. As desribed in this study, an increased PCO might affect the posterior capsular release and laxity during surgery, which can eventually result in de novo hyperextension. Han et al. (15) has also shown a relationship of PCO and PTSA with ROM. According to their study, for cases with more than 3° of PTSA, PCO was negatively associated with ROM. Even though that study mainly discussed flexion, the results of the current study are consistent with it because most of the cases showed a PTSA greater than 3°. However, the current study measured PTSA on plain radiographs, whereas it was measured on CT scans in Han et al. Advanced studies with CT scans would be helpful to further reveal this relationship.

Coronal radiographic parameters

Severe varus alignment, separation of the lateral compartment, and varus recurvatum due to tibial external rotation were described as triple-varus according to Noyes et al. (16) Current patient group could be consistent with triple−varus since most of the patients showed a genu varum deformity and increased preoperative JLCA could indicate a loosened posterolateral complex. Varus recurvatum might be concealed by double limb standing plain radiography, and this deformity could only be revealed after realignment of the lower extremities via TKA.

Moon et al. (17) described in PS TKA that an abrupt increase in medial flexion gaps develops in severe genu varum, despite a gradual medial soft tissue release. Correcting the varus malalignment via the medial soft tissue releasing technique can make the posteromedial soft tissue weak and elongated after operation, which might lead hyperextension of the knee. (7) Sekiya et al. (18) reported that lateral ligament laxity in genu varum showed a reduction at 3 months after TKA, and this could be a reason why not all patients who underwent TKA showed de novo hyperextension via this mechanism.

In addition, de novo hyperextension was found to be significantly associated with increased immediate postoperative JLCA in multivariate model 1 (Table 3). I suggest that this finding could be caused by residual excessive posterolateral ligament laxity, and therefore immediate postoperative JLCA measured on supine plain radiography would be useful in predicting the development of de novo hyperextension.

Increased PTSA is known to increase both the extension gap and the flexion gap during the procedure of TKA. (19) Oka et al. (20) reported increased PTSA affected the flexion−extension gap difference in PS TKA. Adjusting these gap discrepancies might demand extra ligament release in the posterior capsule, which could result in de novo hyperextension. Some authors also addressed the potential deleterious effects of an excessive PTSA. This could induce an increase in paradoxical condylar roll−back in extension, which could result in a consequential decrease in extensor strength. (21) This mechanism would account for the development of de novo hyperextension in extreme post PTSA patients.

In previous studies, the prevalence of hyperextension after TKA has been reported in various ways, from 1.6 to 27.6%. (4, 6, 10, 22) Siddiqui et al. described the incidence of postoperative hyperextension greater than 5° to be 8.2% among 2587 conventional TKAs. (10) Ritter et al. described a 1.6% incidence of hyperextension in 5622 conventional TKAs. (22) On the other hand, the present study reported that the incidence of hyperextensions greater than 5° was only 2.4% in 3864 PS-TKAs. This lower value might be a result of the present definition of hyperextension as 5° or higher, considering the accuracy of the goniometer. It also might be caused by the present definition of de novo hyperextension only developing at least 3 months after TKA. Ritter et al. (22) described preoperative flexion contracture association with postoperative flexion contracture. However, their study only described cases with a normal range of motion, so the results of the current study might explain the extrapolation area of postoperative hyperextension, with a greater range of motion and a low profile of preoperative flexion contracture resulting in postoperative hyperextension in elderly patients with progressed osteoarthritis. In addition, it has been commonly accepted that the presence of osteoarthritis tends to be correlated with less laxity than a normal knee. (23) However, as shown in the present study, there were some arthritic knees that tended to have laxity despite degenerative progression, which requires further study.

Limitations

There were some limitations to this study. First, the accuracy of the measurements was debatable. The goniometer is a well-known estimation apparatus for the evaluation ROM, but it is also known to have an error around 5°. (24, 25) However, I only included cases where hyperextension was observed consistently. Second, different results may have been obtained with another type of prosthesis. Since the surgical and prosthesis concepts would be different for another prosthesis, the clinical outcomes could be different with the same angle of hyperextension in cases of implantation of another type of prosthesis. Because of this point, the present study design ruled out possible bias by matching the types of implants. Third, the mediolateral balance was only evaluated through JLCA, not by other known measurements, such as stress radiographs. (10, 26) Furthermore, immediate postoperative supine anteroposterior view radiography is not reliable for reproducing the same value. Nonetheless, JLCA itself may have predictive value for de novo hyperextension according to the present study, so even without stress radiographs, there are a few measures that can be used to evaluate mediolateral balance. Fourth, I calculated the sagittal alignment according to a short lateral radiograph. In terms of the true sagittal alignment of the lower extremity, it would better to evaluate this with a lateral teleradiograph. However, obtaining a lateral teleradiograph is not always feasible in elderly patients while a short lateral radiography is accessible in every center. In addition, hyperextension of sagittal alignment could be caused by the joints other than knee joint as well. Quadriceps weakness and ankle plantarflexor tightness can be the common casues of knee hyperextension in neurologic impaired patients.(7) In the present study, the hyperextension and control group patient had no history of neurologic deficits. In the future, prospective follow-up studies on large cohorts, including measurements of quadriceps muscle strength, gait pattern and varus, valgus laxity, and lateral teleradiographs are needed. Finally, in multivariate logistic regression analysis, there were some factors that were revealed as insignificant: preoperative flexion contracture, range of motion, and postoperative JLCA, whereas these were significant in univariate logistic regression analysis. Additional studies with a high volume registry would be necessary to determine whether these factors genuinely contribute to the development of de novo hyperextension.

Conclusion

De novo hyperextension after PS TKA is more likely to develop in patients with greater changes in the mechanical axis and medial soft tissue release, greater JLCA, and less PCO. Therefore, surgeons should be aware of these predisposing factors of de novo hyperextension. During surgery, excessive medial soft tissue release to correct the mechanical axis should be avoided. Finally, evidence of residual medial-lateral laxity could predict the development of de novo hyperextension after TKA.

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국문초록

목적: 수술 후 과신전은 인공 슬관절 전치환술 이후 발생하는 치료가 어려운 드문 합병증으로 수술 직후 발생한 과신전이 아닌 추시에 따라 서서히 발생한 과신전에 대해서는 연구된 바가 적다. 본 논문에서는 후방 십자인대 대치형 인공 슬관절 전치환술에서 수술 이후 신생 과신전을 일으키게 되는 임상적, 방사선학적 인자를 알아보고자 하였다.

대상과 방법: 본 연구는 후향적으로 85례의 신생 과신전 발생한 환자 군과 나이, 성별, 집도의, 임플란트 종류를 85례 매칭하여 대조군을 설정한 후 임상적, 방사선학적 지표(기계적 축, 관절선 수렴각, 후방 경골 경사, 대퇴후방과 오프셋, 감마 각)에서 두 군 사이의 차이를 알아보았고 이분형 로지스틱 회귀분석을 통하여 신생 과신전에 기여한 임상적, 방사선학적 지표에 대하여 분석하였다.

결과: 신생 과신전 발생 그룹에서 수술 전 굴곡구축이 더 작았으며 ($p < 0.001$), 더 큰 운동범위 ($p < 0.001$)를 보였다. 방사선학적 지표에서는 수술 전/후 관절선 수렴각이 컸고 (각각 $p = 0.002$, $p < 0.001$), 수술 후 후방 경골 경사(델타 각)가 컸으며 ($p < 0.001$), 수술 전/후 대퇴후방과 오프셋이 작았다. (각각 $p < 0.001$, $p < 0.001$) 이분형 로지스틱 회귀분석에서도 다중공선성을 고려하여 수술 전/후 대퇴후방과 오프셋을 각각 따로 분석한 결과 모두 내측 연부조직 유리가 많이 된 경우 ($p = 0.016, 0.014$), 기계적 축을 많이 교정한 경우 ($p < 0.001$, $p < 0.001$), 수술 전 관절선 수렴각이 컸던 경우($p = 0.023$, $p = 0.023$)에 신생 과신전을 발생시킨 경우와 연관된다는 결과를 보였다.

결론: 본 연구에서 내측 연부조직 유리를 많이 한 경우, 기계적 축을 많이 교정한 경우, 수술 전/후 관절선 수렴각이 큰 경우, 대퇴후방과 오프셋이 작은 경우가 신생 과신전의 위험인자로 밝혀졌다. 따라서 수술자는 진행된 퇴행성 변화가 있음에도 수술 전 운동범위가 큰 환자의 인공 슬관절 전치환술에 있어서 해당 위험인자가 있는 경우 수술에 주의하여야 한다. 수술 후 측정한 관절선 수렴각이 크게 측정된 환자들에선 이런 이완이 남은 경우로 추후 이로부터 신생 과신전의 발생을 예측할 수 있을 것이다.

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주요어: 과신전, 전반슬, 후방십자인대 대치형, 인공 슬관절 전치환술

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