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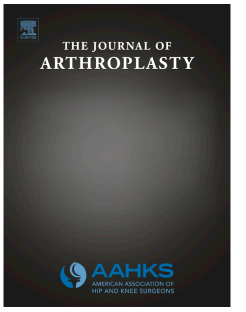

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What is the ideal degree of extension after primary total knee arthroplasty?

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What is the ideal degree of extension after primary total knee arthroplasty?

Abstract

Background: Few studies have examined flexion contracture at the time of primary total knee arthroplasty (TKA) or how flexion contracture changes over time. The purpose of this study was to assess the ideal degree of extension immediately after TKA and to document postoperative changes in extension and clinical outcomes over 5-year follow up.

Methods: This retrospective cohort study included 215 cases of primary TKA. Radiographic evaluations were performed on sagittal radiographs with the patient in the supine position and the knee in gravity and in passive extension using a stress device. Clinical outcomes were also measured. Four groups were defined on the basis of the extension angle during radiological evaluation: Group 1, -10° to 0°; Group 2, >0° to +5°; Group 3, >+5° to +10°; Group 4, >+10° in gravity.

Results: There were statistically significant differences in passive extension and gravity extension angles in groups 1, 3, and 4 with time-dependent and time*group (passive vs. gravity) analyses, but not in group 2. The flexion contracture angles over 10° in gravity were decreased, although over 5° of flexion contracture remained at the final follow-up. Clinical outcomes were worse in groups 1 and 4 at the final follow-up.

Conclusion: An extension angle between 0° and 5° in the passive extension position immediately after TKA can be considered ideal at up to 5 years of follow-up. Patients with flexion contracture greater than 5° in passive extension and patients with hyperextension should be followed to assess whether the condition will worsen.

Level of Evidence: Level Ⅳ

Key Words: Flexion contracture, Hyperextension of TKA, Natural history of flexion contracture, Passive extension of TKA, Ideal extension of TKA

Introduction

The range of motion (ROM) obtained after total knee arthroplasty (TKA) is an important measure of the success of the procedure. Postoperative function and patient satisfaction are associated in part with postoperative ROM. Two recognized complications of TKA are flexion contracture and hyperextension, which reduce ROM or stability and are a source of patient morbidity.[1]

Flexion contracture prevents the knee from achieving full extension. It is thought to result from abnormalities in bony anatomy, as well as soft tissue contracture and tightness around the joint.[2] The incidence of fixed flexion deformity after TKA has been reported to range from 8% to 17%. [3,4] In patients with flexion contracture, a large amount of energy is needed from the quadriceps to help the knee bear load and remain stable. [4] As a result, standing, walking, and stair climbing are abnormally tiring, reducing overall knee function.[4] Despite its high incidence, only a few studies have reported the natural history of flexion contracture. In a study of 369 TKAs, Aderinto et al [5] showed that knee extension continued to improve up to 3 years after TKA, but they did not report the factors that led to improved flexion contracture. Quah et al [6] reported that flexion contracture less than 15° can improve up to 2 years after TKA. Nonetheless, there is still no consensus about the ideal degree of extension during surgery to achieve appropriate extension at follow-up, and little is known about the natural history of flexion contracture.

Hyperextension is an unusual problem after TKA because it is associated with valgus deformities and ligamentous laxity in patients with rheumatoid arthritis (RA), with previous high tibial osteotomy (HTO), and with neuromuscular disorders such as poliomyelitis.[2,4,7] According to Shultz SJ et al [8], hyperextension deformity in the normal knee was associated with decreased work absorption and stiffness, resulting in increased contact force and posterior capsular laxity. However, few studies have focused on the role of knee extension after TKA due to the rarity of the condition.[1,9-11] Therefore, the incidence of hyperextension and functional acceptability has not been well documented. Siddiqui et al[11] presented a grading system for hyperextension and identified postoperative mediolateral laxity as a risk factor for hyperextension after TKA.

The purpose of this study was to determine the ideal degree of extension after primary TKA and to identify postoperative changes in extension and clinical outcomes at a minimum of 5 years of follow up. We hypothesized that fixed flexion contracture over 5° would be associated with worse clinical outcomes. We also investigated the factors that cause unacceptable hyperextension or flexion contracture in terms of function.

Materials and Methods

This was a retrospective study that was performed prospectively and approved by the institutional review board of our institute. Patients who were scheduled for primary TKA were enrolled after providing informed consent. From December 2009 to December 2011, the senior author performed TKA on 368 primary patients using the NexGen LPS-flex system. The inclusion criteria were degenerative knee arthritis, use of spinal anesthesia which could be prolonged anesthesia status after surgery to exclude neuromuscular effects. The exclusion criteria were as follows: bone graft due to severe deformity or bone defect, rheumatoid arthritis, previous spinal surgery that could affect the assessments, revision surgery, varus/valgus deformity greater than 20°, BMI over 30 kg/m^2, and other neuromuscular disease. After applying these inclusion and exclusion criteria, 215 primary TKAs in 186 patients (35 males and 151 females) were included, comprising 29 patients (58 knees) with bilateral TKA and the same type of prosthesis on both sides. Preoperative demographic data are summarized in Table 1.

Each knee was rated with the Knee Society Knee Score (KSKS), Knee Society Functional Score (KSFS), and the Hospital for Special Surgery (HSS) scoring systems. Moreover, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) health status questionnaire was performed by each patient. The active maximal flexion and extension angles were measured using a goniometer with the patient in the supine position. Goniometers are commonly used to measure ROM and have good to excellent reproducibility [12,13].

The primary TKAs were performed using a conventional technique with a tourniquet applied [14]. After an anterior midline skin incision, a standard medial parapatellar arthrotomy was performed. An intramedullary guide was used for the femur, while an extramedullary guide was used for tibia resection. The depth for distal femoral resection started at 9 mm, but greater resection was performed when flexion contracture remained, even though all soft tissue balancing and bone resection were completed. The depth for tibia resection was around 10 mm, using the highest point of the lateral tibia plateau as a reference point. After the anteroposterior (AP) cut was completed with a femoral cutting block guide, the flexion gap was measured. If the flexion gap was larger than the extension gap, the femoral block was set 2 mm posterior to its initial position. The medial and lateral flexion gap differences were accepted at less than 2 mm according to a laminar spreader for gap measurement. The PCL was resected, and the patella was resurfaced in all cases. All prostheses were fixed with cement.

Radiologic Evaluations

Radiographic evaluations were performed routinely after surgery; at 3 months, 6 months, and 1 year after surgery; and annually thereafter. For the sagittal radiographs, the proximal tibial and distal femoral diaphyseal axis, defined as the line connecting the midpoints of the outer cortical diameter at 5 cm and 15 cm proximal to the joint line, was used for measuring the sagittal extension angle. It remains controversial as to which point or axis reveals the true mechanical axis or ROM; the diaphyseal axis used in this study has high reproducibility and allows an easy technique.[15-18]

Moreover, specialized radiographic evaluations were performed on sagittal radiographs with the patient in the supine position and the knee in gravity and in passive extension immediately after surgery and during the follow-up period to assess the change in the degree of flexion contracture. The sagittal radiograph in the gravity position was obtained on the usual lateral radiograph with the patient lying in the supine position. The sagittal radiograph in passive extension was obtained using a Telos® device (Telos GmbH® Laubscher, Holstein, Switzerland) at 150 N with the patient lying in a slightly lateral position (Fig. 1a,b). The radiographs immediately after surgery were performed after skin closure while the patient remained under spinal anesthesia in order to reduce error caused by pain or swelling. We hypothesized that the passive extension sagittal radiograph represented the true extension degree or the potential for further extension, so we assessed its relationship to final flexion contracture. The posterior tibial slope angle, femoral component sagittal position, and the change in the joint line level were also assessed. The joint line level was defined as the distance from the distal femoral condyle to the tibial tuberosity on the lateral radiograph [19]. The change in posterior condylar offset [3] was evaluated by determining the difference between pre- and postoperative values (Figs. 2a,b).

Four groups were defined on the basis of the sagittal extension angle in gravity immediately after TKA: Group 1, -10° to 0° (hyperextension); Group 2, >0° to +5°; Group 3, >+5° to +10°, Group 4, >+10°.

Statistical Analysis

Statistical analyses were conducted with SPSS for Windows version 19.0 (SPSS, Chicago, IL, USA) and G*power analysis (version 3.1.5). The primary outcome measure for this study was the difference in mean extension angle during follow-up for each group, as calculated with repeated measures ANOVA (RM ANOVA). We accepted α error of 5% and β error of 20% to detect any significant difference. To calculate the post hoc sample size for each group, groups 1, 3, and 4 were evaluated because a significant difference was found between these groups when using RM ANOVA and within-subject tests, but no differences were found for group 2. Based on this calculation, the required sample size for group 1 was 40 with 0.5586411 of effect size and 0.237851283 of eta squared value. The required sample size for group 3 was 48 with 0.5179652 of effect size and 0.2115355 of eta squared value. The required sample size for group 4 was 20 with 0.8821951 of effect size and 0.43765513 of eta squared value.

Differences in patient demographics among the groups were analyzed with chi-square test for categorical variables and one-way ANOVA for continuous variables in order to identify predictors for the occurrence of flexion contracture or hyperextension. Multivariate regression analysis was performed to identify factors that affect the change of degree by passive extension force immediately after surgery and that affect the improvement of the degree of flexion contracture in the gravity position in groups 3 and 4. Moreover, paired t-test and one-way ANOVA were used to compare values immediately after surgery and during the follow-up period. Time-dependent data were analyzed with 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. Statistical significance was set at $p < 0.05$. The reliability of measurements was assessed with the intraclass correlation coefficient (ICC), which quantifies the proportion of the variance due to variability between measurements. A test-retest for intraobserver reliability was performed by each orthopedic surgeon 3 weeks after the first measurement, and the intraclass correlation coefficient was determined (ICC).

Results

Radiographic Analysis

The overall time-dependent mean values of the sagittal extension angle are summarized in Table 2. The RM ANOVA analysis revealed statistically significant differences in passive extension and gravity extension angles in groups 1, 3, and 4 with time-dependent and time*group (passive vs. gravity) analyses ($p < 0.001$). (Fig. 3a, b, c, d) However, these angles did not differ significantly in group 2 according to RM ANOVA with time-dependent and time*group (passive vs. gravity) analysis (p = 0.683/ 0.830, Greenhouse-Geisser method).

The mean sagittal extension angle was significantly different between gravity and passive extension immediately after surgery in all groups; however, these differences were not significant after 1 year of follow-up. Moreover, the groups that showed flexion contracture greater than 5° in gravity had significantly decreased angles at 1 year. However, the angle in passive extension in groups 2, 3, and 4 did not differ significantly during follow-up, while group 1 showed a decreased hyperextension angle in passive extension. (Table 2)

For the hyperextension group, the mean sagittal extension angle was significantly different between gravity and passive extension immediately after surgery. However, at 1 year after surgery, the mean sagittal extension angle in gravity and passive extension did not differ significantly; moreover, the mean sagittal extension angle in passive extension was significantly lower 1 year after surgery than during the immediate postoperative period. For patients with hyperextension, their operated limbs remained in hyperextension regardless of the position at final follow-up, even though a decreased value of extension was found. (Table 2)

The results of the other specialized radiographic analyses are summarized in Table 3. All of these values and preoperative demographics were evaluated for their effects on postoperative flexion contracture and hyperextension by entering in a stepwise multiple regression analysis. The change in posterior condylar offset value predicted the change in degree of passive extension force immediately after surgery (adjusted $R^2 = 0.251$, intercept = -2.243, B = -0.521, SE(B) = 0.62, $\beta = -0.501$, $p < 0.0005$). Moreover, the overall change in the value of the posterior condylar offset was negatively correlated with the change in the value of the degree of extension by passive extension force immediately after surgery (Pearson correlation coefficient, $r = -0.501$, $p < 0.001$) (Fig. 4). These results indicate that the decreased posterior condylar offset values could affect the posterior capsular tension immediately after surgery, changing the flexion contracture angle due to stress force.

The mean difference between the sagittal extension angle in gravity and passive extension immediately after surgery, preoperative demographics, and the other values summarized in Table 3 were entered to stepwise multiple regression analysis to evaluate the factors associated with improved flexion contracture in gravity for groups 3 and 4. The mean difference in passive extension force immediately after surgery was the only factor that explained the resolved value of flexion contracture in the gravity position, but this factor had weak predictive value (adjusted $R^2 = 0.021$, intercept = -3.848, B = -0.324, SE(B) = 0.203, $\beta = -0.185$, $p = 0.01$).

The ICC for inter- and intra-observer reliability was greater than 0.7, ranging from 0.79 to 0.91, for all measurements, indicating good inter-observer reliability.

Clinical Analysis

The overall clinical results are summarized in Table 4. The preoperative clinical results did not differ significantly among groups. The final clinical results also did not differ significantly among groups, with the exception of the KSKS and KSFS scores (Table 4). The final KSKS scores differed significantly between groups 2 and 1 ($p = 0.033$) and between groups 2 and 4 ($p = 0.019$). There were no significant differences among the other groups. The final KSFS scores also differed between groups 2 and 1 ($p = 0.036$) but did not differ significantly among any other groups (Table 5).

The overall time-dependent mean values of the KSKS and KSFS scores are summarized in Table 5. The RM ANOVA analysis revealed that KSKS and KSFS scores changed significantly over time in all groups. ($p < 0.001$) (Fig. 5a,b). The mean KSFS score in group 4 improved after surgery, but started to decrease at 5 years after surgery ($p = 0.038$, compared the scores of 3 years and 5 years). The mean KSKS scores in group 4 also improved after surgery and decreased at 5 years after surgery, although not significantly. The mean KSFS score in group 1 improved after surgery and decreased at 5 years after surgery compared with the scores at 2 years after surgery ($p = 0.036$), although there were no significant differences between the scores at 3 years and 5 years. There were no differences in the mean KSKS scores during follow-up in group 1. There were no cases of revision during the study.

Discussion

The most important finding of this study was that, after 5 years of follow-up, the patients with flexion contracture less than 10° immediately after surgery in the gravity position obtained the appropriate extension of less than 5° in both the gravity and passive extension positions. Furthermore, even though flexion contracture was over 10° in the gravity position immediately after surgery, it improved during follow-up. The absolute value of passive extension immediately after surgery could reflect the final extension status because no statistical differences were found between the angles of flexion contracture in gravity and passive extension during follow-up. Moreover, the range of 0° to 5° in passive extension immediately after surgery can be considered the ideal degree of extension to predict the final extension angle up to 5 years after surgery because all extension angles remained within 5°. Moreover, hyperextension persisted during follow-up, with decreased clinical outcomes.

Postoperative flexion contracture can lead to poor clinical outcomes by altering the biomechanics and load bearing of the knee [4]. Although the success rate of TKA is high, full extension is not consistently achieved during the operation. Flexion contracture immediately after TKA is usually caused by pain and effusion [20,21] and is known to resolve with time. Kim et al.[22] investigated extrinsic and intrinsic factors for flexion contracture after TKA and found that arthrofibrosis due to postoperative scarring was a common cause of unresolved flexion contracture [22,23]. Although the deleterious effects of flexion contracture are well documented, there is debate about their resolution over time and the need for surgical intervention. Moreover, there is still no consensus on which angle is most appropriate immediately after surgery to attain full extension at final follow-up. It has been commonly believed that a flexion contracture in the arthritic knee must be completely corrected during surgery, and that a flexion contracture that is present at the end of the operative procedure is unlikely to resolve [4,24]. However, studies have shown that knees with a small preoperative flexion contracture can show increased flexion deformity after surgery but improvement during follow-up; those with more severe degrees of preoperative flexion contracture gained immediate improvement [3]. A similar pattern has been observed in relation to the flexion range after TKA [2,11,25].

Our findings indicate a tendency for flexion contracture in the gravity position to improve up to five years after surgery, consistent with the findings of Aderinto et al [5] and McPherson et al[2]. Moreover, our findings suggest that flexion contracture over 5° in passive extension could be a risk factor for ongoing postoperative flexion contracture. Meanwhile, our findings are inconsistent with some previous studies [1,5,12]. Previous knee extension data have shown that patients with large flexion contractures preoperatively are more likely to experience a flexion contracture postoperatively. They also identified sex and older age as risk factors and quantified the risk in each case. In the current study, these variables were not identified as risk factors for postoperative flexion contracture in multiple regression analysis. Because the preoperative degree of flexion contracture was relatively small and did not differ among the groups, the importance of that factor could have been underestimated in our statistical analysis. On the other hand, the absolute angle in the passive extension position immediately after surgery could predict the values of those angles at final follow-up. This means that there could be misdiagnosis about flexion contracture in the gravity position immediately after surgery; instead, the angle in the passive extension radiograph could be used. Our data suggest that the ideal angle in the passive extension position immediately after surgery is between 0° to 5°.

Interestingly, our findings suggest that patients with initial hyperextension in the gravity and passive extension positions will remain in hyperextension at final follow-up. Unlike postoperative flexion, hyperextension after TKA has not been well studied; only special conditions for difficult TKA have been studied [1,8-11]. In a prospective study of 2,589 conventional TKAs, Siddiqui et al.[11] reported the incidence of postoperative hyperextension over 5° to be 4.6%. They reported that patients with hyperextension at 6 months were 6.5 times more likely to have hyperextension at 2 years, and patients with a postoperative Medio-lateral laxity greater than 5 mm were more likely to have hyperextension greater than 5°. Reduced functional outcomes were associated with increased hyperextension deformity greater than 5° in that study. In our study, 3.2% of patients (7/215) had hyperextension over 5° at final follow-up, but the incidence of residual hyperextension between 0° to 5° was 12.6% (27/215). Nine cases were not measured as hyperextension at final follow-up. However, predictors of hyperextension were not found in regression analysis. Perhaps this occurred due to measurement error from the radiographs and goniometer, in which the cases between 0° to 5° might not have been considered as real hyperextension with the goniometer. However, the clinical outcomes as measured by the KSFS decreased during follow-up, and the KSKS scores were also lower than those in the ideal extension group, group 2. Moreover, 79.1% (34/43) of patients with hyperextension continued to have hyperextension during follow-up. Thus, we believe that hyperextension in primary TKA should be avoided. Further study with a longer follow-up is needed to confirm this result.

A decreased value of condylar offset of the posterior femoral condyle compared with the preoperative value was a factor for changing the degree by passive extension force immediately after surgery. Mitsuyasu et al.[26] found that an enlarged posterior femoral component reduces the extension gap, suggesting that the posterior femoral condylar offset might cause a reduction in the extension gap due to posterior tissue tightness. Since the overall changed value of the posterior condylar offset was negatively correlated with the changed degree by passive extension force and was analyzed as a factor of change by passive extension force, posterior capsular laxity might be a cause of hyperextension immediately after surgery. However, in this study, a decrease in hyperextension deformity during follow-up could be associated with healing potential of posterior capsular laxity, regardless of whether the posterior condylar offset was decreased or not.

The final KSKS scores were lower in the hyperextension group (Group 1) and the severe flexion contracture group (Group 4) compared with the ideal extension group (Group 2). In addition, the final KSFS scores in the hyperextension group were lower than those of the ideal extension group at final follow-up (Table 5). In the time-dependent analysis and post hoc analysis during follow-up in each group, the KSFS scores were also decreased in the hyperextension and severe flexion contracture groups. Because clinical outcomes as measured with the KSS score started to decrease after 3 years, and significant differences were found at 5 years after surgery in the hyperextension and severe flexion contracture groups, close follow-up should be performed in such patients, although other scores did not change significantly over time. Moreover, although the tendency for patients to remain in hyperextension or severe flexion contracture decreased somewhat over time, it is possible that the clinical outcomes could worsen with a longer follow-up.

This study had a number of limitations. First, the accuracy of measurements was controversial. Measurement of the diaphyseal axis used in this study has high reproducibility and involves an easy technique, but it remains controversial whether this axis angle correlates with true ROM. Many studies have measured ROM with a goniometer and confirmed its usefulness [12,13,15]; however, there is still no standard technique or standard point to measure ROM on radiologic film. Nonetheless, since previous studies have shown no or minimal differences among the sagittal axis of the radiograph [16,17,27], the diaphyseal axis was used for this study. Second, the study population was relatively small because many groups were investigated although the power of the study was achieved. Moreover, the study population included typical cases of TKA because patients with a larger BMI were excluded. Other factors could affect hyperextension or flexion contracture, such as a larger BMI, gender, or bilaterality, but these factors might be statistically underestimated in our study due to the small number of patients in each group. Moreover, there could be ethnic differences in laxity or stiffness after TKA, so long-term follow-up and a larger cohort size should be planned to evaluate changes in flexion contracture or hyperextension. Finally, the specialized radiographic evaluation of laxity of the posterior structure was not obtained preoperatively. Further study is needed to evaluate the preoperative status of the posterior structure and its association with the improvement of flexion contracture or hyperextension.

Conclusion

An extension angle between 0° to 5° in passive extension immediately after TKA can be considered the actual degree of extension that will be achieved over up to 5 years of follow-up. Patients with flexion contracture greater than 5° in passive extension or hyperextension should be cautiously followed to determine whether the condition will worsen.

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Table 1. Demographic data of each groups.(Mean ± Standard Deviation)

	Group 1	Group 2	Group 3	Group 4	P-value¶
Cases	43	97	53	22	-
Age (year)	68.8 ± 6.7	67.8 ± 7.3	70.3 ± 11.9	69.8 ± 9.5	0.38
Gender(Male/Female)	5/33	18/67	8/33	4/18	0.078
BMI(Kg/m^2)	25.2 ± 4.8	25.1 ± 3.6	26.5 ± 5.3	26.3 ± 5.1	0.24
Average Follow-up (months)	63.8 ± 2.5	63.2 ± 3.9	64.0 ± 3.8	64.9 ± 2.3	0.176
Preoperative Clinical Data					
Flexion contracture	7.6° ± 6.5	7.9° ± 7.8	7.8° ± 8.9	8.9° ± 9.6	0.939
Further Flexion	122.7° ± 9.1	124.7° ± 18.0	121.5° ± 15.8	122.1° ± 18.5	0.666
Mechanical axis deviation (Varus)	14.3° ± 5.7	13.6°± 9.3	13.2°±9.5	14.5°±10.2	0.906
KSS score					
KSKS	51.6 ± 13.7	52.3 ± 15.1	51.7 ± 15.9	51.3 ± 12.6	0.987
KSFS	44.7 ± 15.1	41.3 ± 12.4	42.6 ± 13.2	40.3 ± 17.8	0.515
HSS score(Total)	57.4 ± 9.5	56.5 ± 15.6	53.4 ± 12.5	53.6 ± 22.1	0.458
WOMAC score (Total)	33.5 ± 6.8	38.8 ± 14.6	38.3 ± 13.8	39.0 ± 17.3	0.169

Table 2. Radiologic data for neutral extension and passive extension (Mean ± Standard Deviation)

	Initial		POD 1Y		POD 2Y		POD 3Y		POD 5Y		
	Gravity extension	passive extension	Gravity extension	passive extension	Gravity extension	passive extension	Gravity extension	passive extension	Gravity extension	passive extension	P-Value ¶¶
Group1	-2.9°±2.3	-6.8°±3.8	-3.0°±2.2	-3.9°±2.5	-2.8°±2.6	-3.8°±2.7	-2.5°±3.7	-3.7°±4.7	-2.7°±3.8	-4.1°±3.9	<0.0005/ <0.0005
P-Value ¶	<0.0005		0.08		0.084		0.192		0.1		
Group 2	2.2°±1.5	1.4°±2.4	2.2°±3.1	1.4°±3.4	2.0°±2.9	1.3°±2.7	2.1°±3.1	1.3°±3.5	1.9°±3.1	1.3°±3.2	0.683/ 0.830
P-Value ¶	0.006		0.09		0.08		0.09		0.186		
Group 3	7.3°±1.6	3.6°±2.3	4.9°±5.5	3.2°±5.8	3.7°±4.1	2.8°±3.5	3.7°±3.6	2.9°±4.2	3.3°±3.4	2.6°±4.5	<0.0005/ 0.007
P-Value ¶	<0.0005		0.125		0.227		0.294		0.368		
Group 4	13.5°±3.5	8.4°±3.1	8.0°±1.5	7.4°±2.1	7.5°±2.2	7.3°±1.9	7.7°±3.5	7.3°±3.1	7.5°±3.0	7.2°±3.0	<0.0005/ <0.0005
P-Value ¶	<0.0005		0.282		0.749		0.69		0.74		

¶ P-value : For gravity and passive extension in each period.

¶¶ P-value : For RM ANOVA (Time/Time*Group)

Table 3. Specialized postoperative radiographic data (Mean ± Standard Deviation)

Group	Change (initial gravity to passive)	Condylar off set change(mm)	Tibial slope	Joint line Elevation(mm)	Femoral component sagittal position	Preop Flexion Contracture
Group 1	-3.8°±2.8	2.6±1.9	5.7°±1.4	2.3±5.1	1.3°±1.9	7.6°±6.5
Group 2	-0.8°±2.0	-0.1±2.1	5.7°±1.5	2.4± 3.1	1.5°±1.8	7.9°±7.8
Group 3	-3.7°±1.7	1.4±2.9	5.9°±1.4	2.1±2.7	1.8°±1.6	7.5°±8.9
Group 4	-5.1°±2.8	2.7±1.9	5.3°±0.8	2.2±4.8	2.1°±1.9	8.9°±9.6
Overall	-2.5°±2.7	0.52±2.6	5.8°±1.4	2.3±3.4	1.8°±2.8	7.9°± 8.3

Table 4.Clinical outcomes for Each Groups at final follow up (Mean ± Standard Deviation)

Group	Preop KSKS	Preop KSFS	Postop KSKS	Postop KSFS	Preop HSS	Postop HSS	Preop WOMAC	Postop WOMAC
Group 1	51.6 ± 13.7	44.7 ± 15.1	91.4±9.1*	84.4±12.0*	57.4 ± 9.5	87.9±14.2	33.5 ± 6.8	11.7±6.9
Group 2	52.3 ± 15.1	41.3 ± 12.4	96.8±4.5*	91.9±8.6*	56.5± 15.6	93.1±12.8	38.8 ± 14.6	9.8±5.6
Group 3	51.7 ± 15.9	42.6 ± 13.2	93.9±9.9	88.2±11.7	53.4 ± 12.5	90.7±12.4	38.3± 13.8	10.2±5.6
Group 4	51.3 ± 12.6	40.3 ± 17.8	88.5±13.3*	84.7±11.2	53.6 ± 22.1	86.4±13.4	39.0± 17.3	12.2±3.9
P-value¶	0.987	0.515	<0.0005*	<0.0005*	0.458	0.057	0.169	0.149

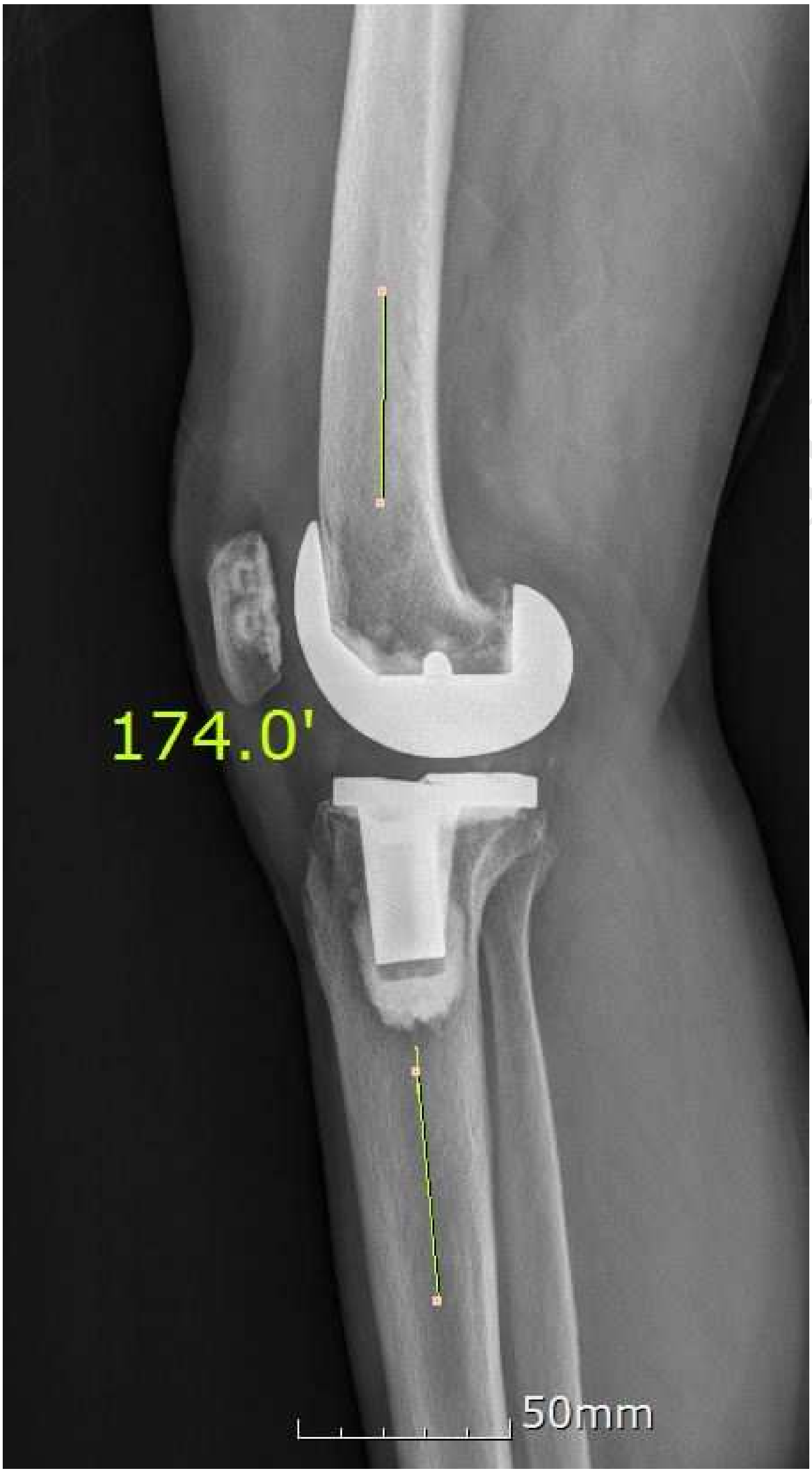
¶ P-value for one-way ANOVA

¶¶All groups were statistically different in paired t-test for preoperative and postoperative values.

Table 5. KSKS and KSFS scores at Each Follow-up Period. (mean± standard deviation)

		Initial	POD 1Y	POD 2Y	POD 3Y	POD 5Y
KSKS	Group 1	51.6 ± 13.7	93.7±5.8	92.9±7.3	91.0±7.9	91.4±9.1*
	Group2	52.3 ± 15.1	96.9±3.0*	95.3±4.3	95.3±4.6*	96.8±4.5*/**
	Group 3	51.7 ± 15.9	95.7±4.4	95.9±3.8	94.1±6.6	93.9±9.9
	Group 4	51.3 ± 12.6	92.9±7.7*	93.6±4.6	91.9±4.5*	88.5±13.3**
P-value¶		0.987/ NC	0.023/0.032*	0.09/NC	0.033/0.036*	<0.0005/0.033*/0.019**
KSFS	Group 1	44.7 ± 15.1	88.3±6.6	89.2±6.4*	88.5±6.4	84.4±12.0*
	Group2	41.3 ± 12.4	93.2±4.9	93.6±4.5*	92.4±5.2	91.9±8.6*
	Group 3	42.6 ± 13.2	90.1±9.9	90.5±7.2	90.1±8.0	88.2±11.7
	Group 4	40.3 ± 17.8	89.4±4.9	90.8±4.7	89.9±5.4	84.7±11.2
P-value¶		0.515/ NC	0.052/ NC	0.039/0.025*	0.134/ NC	<0.0005/0.036*

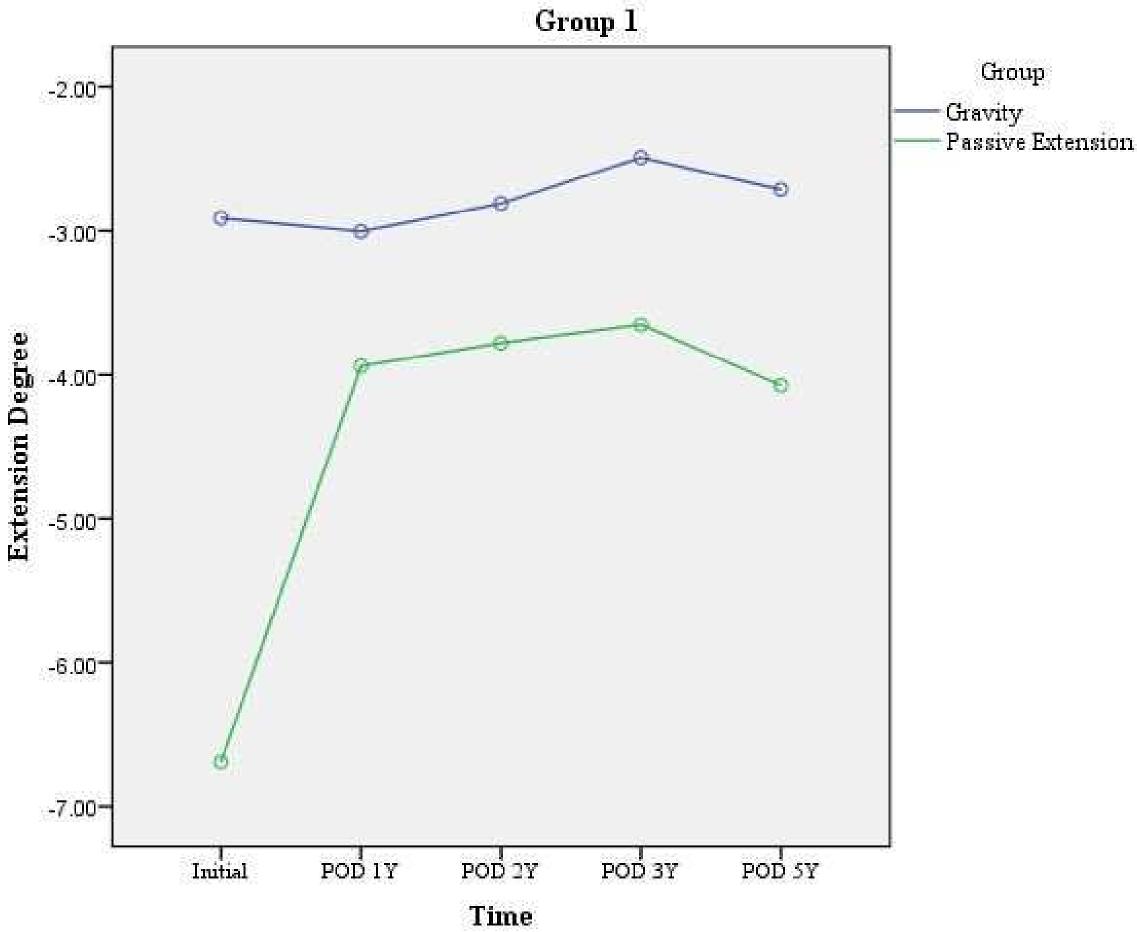
¶P-value : value for One-way ANOVA for each period/value for post hoc analysis between marked groups* at each period

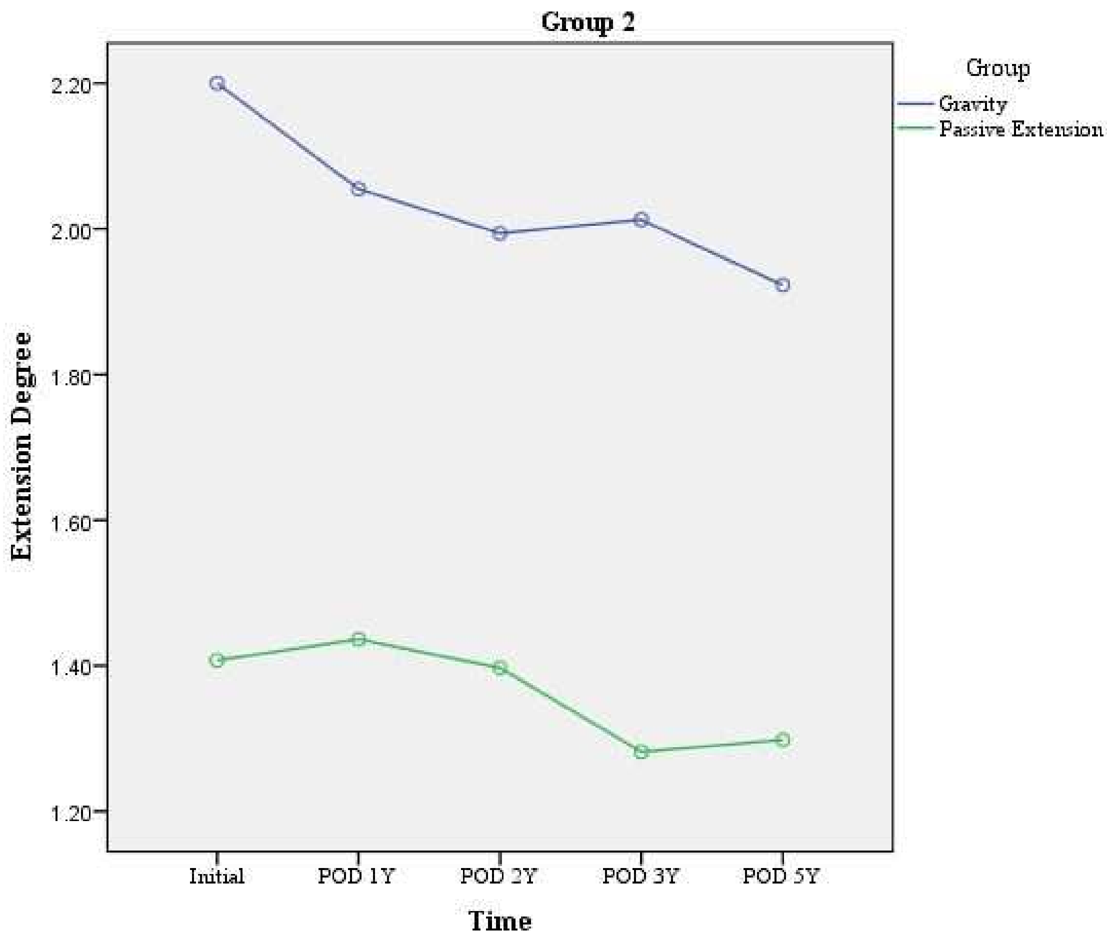

174.0'
50mm

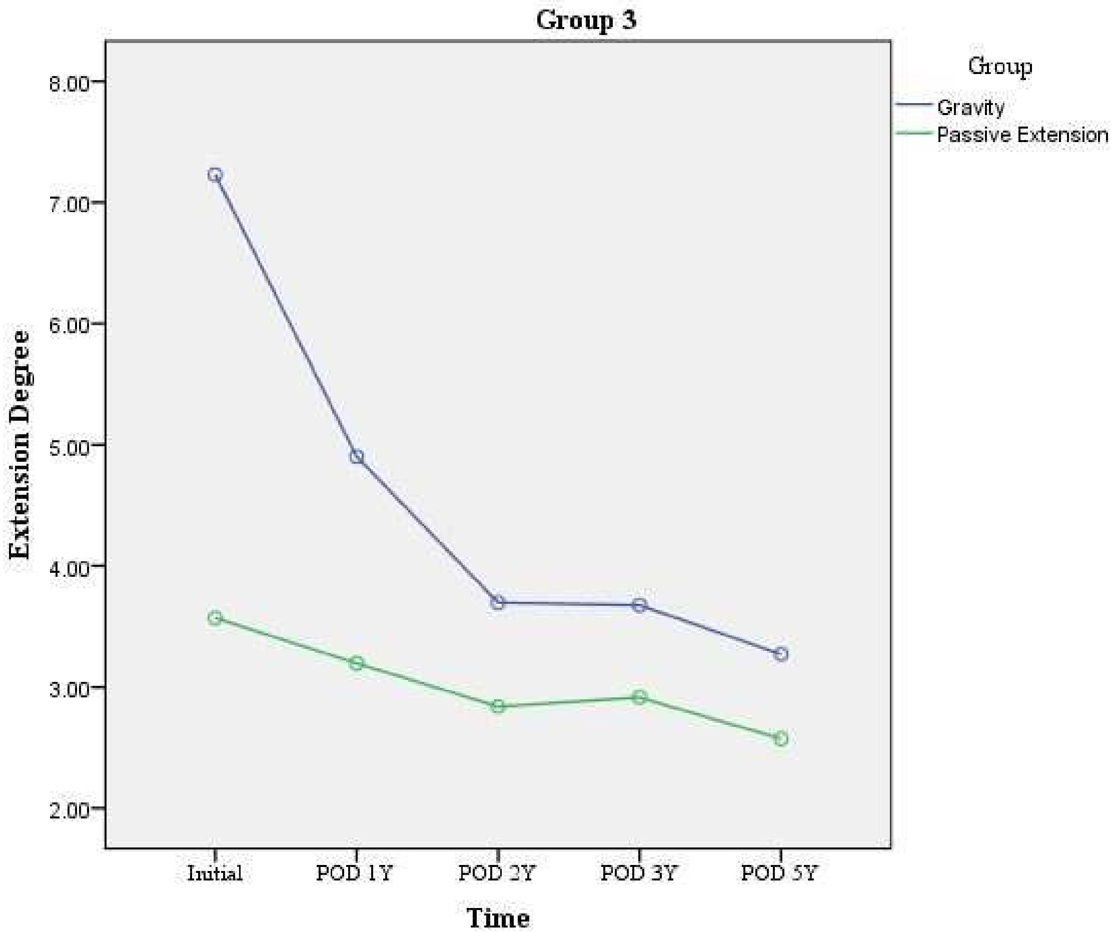

1.1'

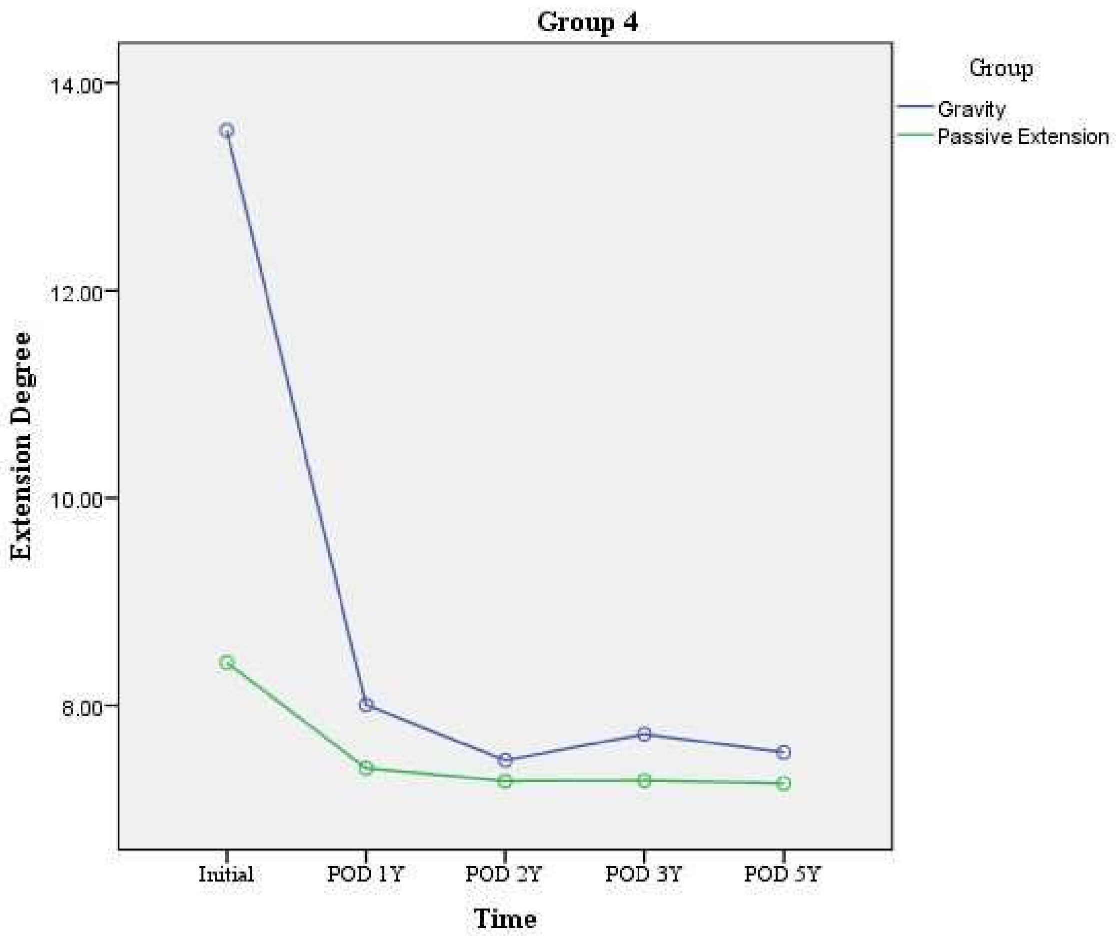

29.40 mm


31.50 mm

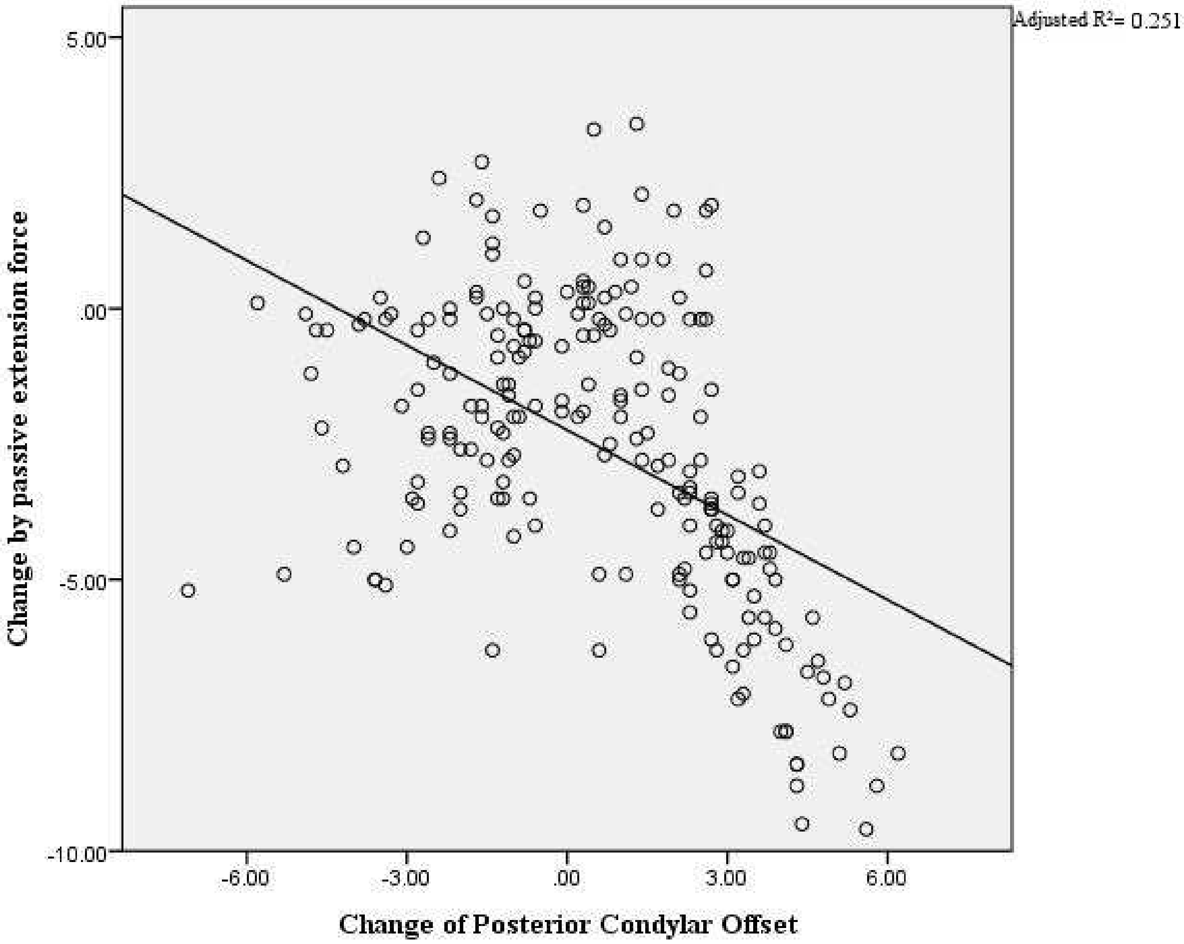

Group 1
Group
Gravity
Passive Extension
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
Extension Degree
Initial
POD 1Y
POD 2Y
POD 3Y
POD 5Y
Time


Group 2
2.20
2.00
1.80
1.60
1.40
1.20
Extension Degree
Group
Gravity
Passive Extension
Initial
POD 1Y
POD 2Y
POD 3Y
POD 5Y
Time

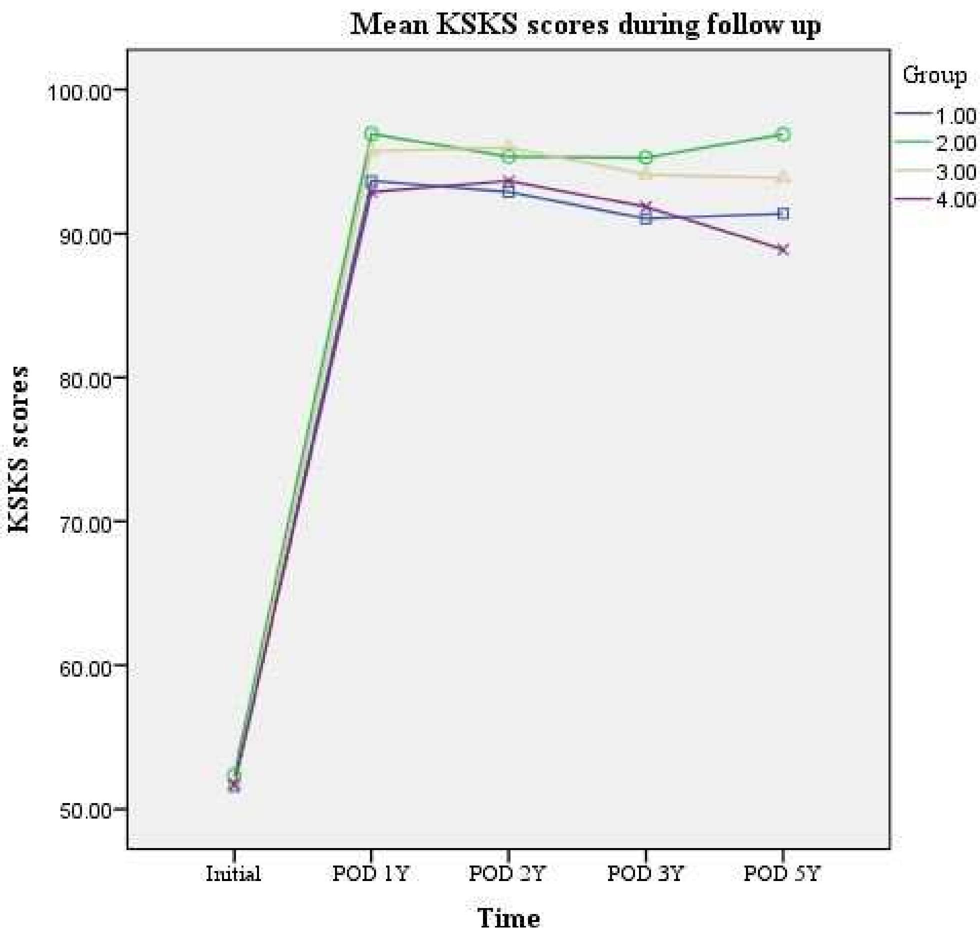

Group 3
Group
Gravity
Passive Extension
Extension Degree
8.00
7.00
6.00
5.00
4.00
3.00
2.00
Initial
POD 1Y
POD 2Y
POD 3Y
POD 5Y
Time



Group 4
Extension Degree
14.00
12.00
10.00
8.00
Initial
POD 1Y
POD 2Y
POD 3Y
POD 5Y
Time
Group
Gravity
Passive Extension



Adjusted R²= 0.251
5.00
.00
-5.00
-10.00
-6.00
-3.00
.00
3.00
6.00
Change by passive extension force
Change of Posterior Condylar Offset


Mean KSKS scores during follow up
Group
1.00
2.00
3.00
4.00
100.00
90.00
80.00
70.00
60.00
50.00
KSKS scores
Initial
POD 1Y
POD 2Y
POD 3Y
POD 5Y
Time

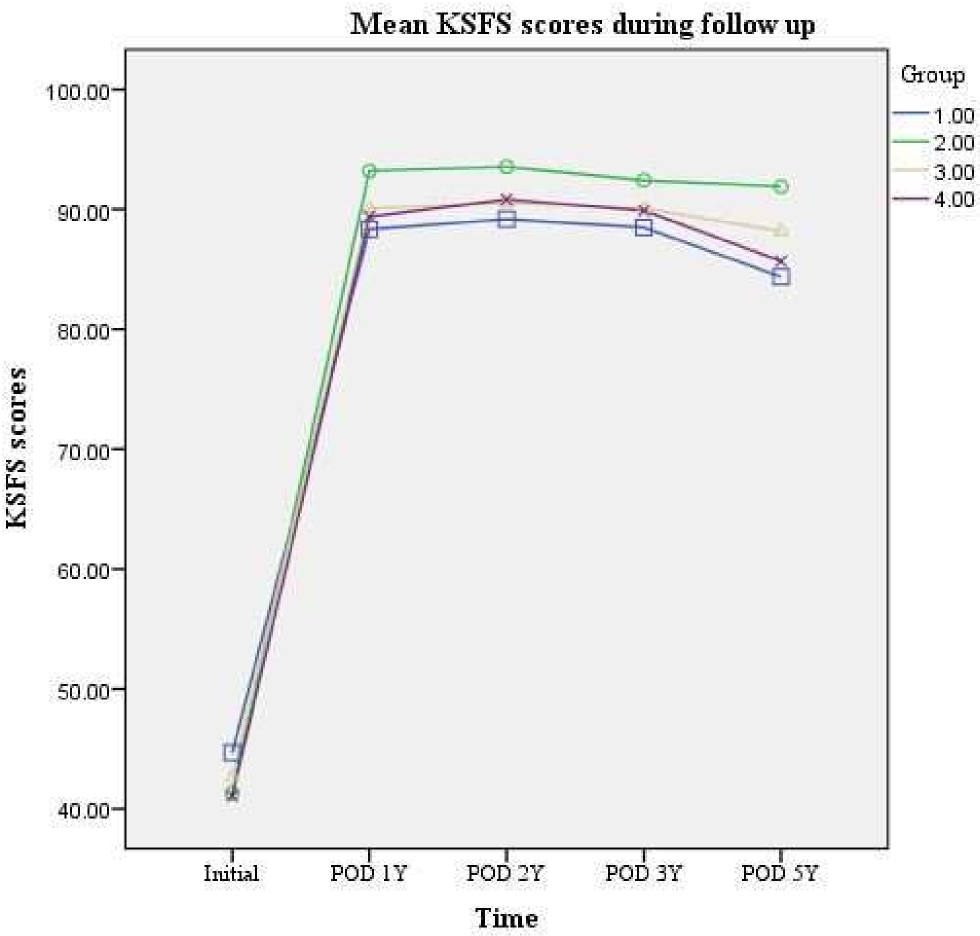

Mean KSFS scores during follow up
Group
1.00
2.00
3.00
4.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
KSFS scores
Initial
POD 1Y
POD 2Y
POD 3Y
POD 5Y
Time

Figure Legends

Fig.1. The sagittal diaphyseal axis angle was measured for extension angle in gravity and passive extension position. a) extension angle in gravity b) extension angle in passive extension positioin

Fig.2. The posterior condylar offset change was defined as change of preoperative and postoperative distance from posterior cortical margin of femur to posterior condylar articulation. a) Preoperative condylar off set distance. b) Postoperative condylar off set distance.

Fig. 3 The time dependent data of extension angles a) The degree of hyperextension in passive extension position was decreased. b) The degree of flexion contracture was not changed during follow up. c) The degree of flexion contracture in gravity was decreased, but the degree of flexion contracture in passive extension position was not changed during follow up. d) The degree of flexion contracture in gravity was also decreased, and the degree of flexion contracture in passive extension position was also not changed during follow up.

Fig.4. Overall correlation of the changing value of posterior condylar offset distance and changing degree of extension by passive extension force. ($r= -0.501$, $p<0.001$)

Fig. 5 The overall time-dependent mean values of the KSKS and KSFS scores were shown. a) The time-dependent KSKS scores were shown. The KSKS scores in group 4 started to decrease after 5 years of follow up. b) The time-dependent KSKS scores were shown. The KSFS scores in group 1 also started to decrease at 5 years.