



# Gradual change in knee extension following total knee arthroplasty using ultracongruent inserts

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## ABSTRACT

**Background:** Total knee arthroplasty (TKA) using an ultracongruent (UC) insert is widely performed. Lack of the posterior cruciate ligament or post-cam mechanism is a concern in terms of range of motion. The flexion angle of UC TKA had been well investigated; however, natural history and correlation factors of the postoperative extension angle have not been well documented. This study aimed to investigate time-dependent changes in extension after TKA using UC inserts, and to evaluate factors that correlated with the postoperative extension angle. **Methods:** This study reviewed 388 gap-balanced UC TKAs (331 patients) without hyperextension at navigation and performed between November 2010 and December 2014. The extension angle (a positive number indicates hyperextension) was measured on full-extension lateral radiographs. The extension angles from five days post-operation to final follow-up were investigated. Factors correlated with the postoperative extension angle were evaluated using multiple regression analysis.

**Results:** Mean follow-up duration was 46.2 months. Until two years, the extension angle gradually increased; mean angles at five days/six months/one year/two years/and final follow-up were:  $-9.2^\circ/-2.6^\circ/0.6^\circ/1.0^\circ/1.0^\circ$ , respectively. Female sex ( $\beta = -0.15$ ,  $P = 0.002$ ) and pre-operative hyperextension ( $\beta = 0.31$ ,  $P < 0.001$ ) were associated with postoperative hyperextension deformity.

**Conclusions:** Following UC TKA, knees became gradually more extended until two years post-operation. Sex and pre-operative extension angle were predictive factors for the postoperative extension angle following UC TKA.

Level of evidence: Level 4, Case series.

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## 1. Introduction

Ultracongruent (UC) polyethylene inserts have been introduced, with standard femoral components, as substitutes for the posterior cruciate ligament (PCL) during total knee arthroplasty (TKA). This design conforms to the femoral component with an ad-

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ditional raised anterior lip to prevent anterior femoral translation during knee flexion. Additional bone cutting for the notch is unnecessary and it is free from the problems inherent to the post-cam mechanism [1,2]. However, due to high congruency of a fixed insert, non-physiologic femoral rollback and reduced axial rotation are often observed [3]. Moreover, it is concerning that hyperextension cannot be prevented by the PCL or femoral component-anterior post, unlike cruciate-retaining (CR) or posterior-stabilized (PS) TKA [4,5]. However, some recent studies have demonstrated clinical outcomes similar to those of PS TKA [1,6,7].

The postoperative range of motion (ROM) is associated with patient satisfaction and postoperative function after TKA [8]. Obtaining enough flexion is important, as is avoiding flexion contracture or hyperextension for postoperative ROM. For CR or PS TKA, previous studies have reported that persistent postoperative flexion contractures and hyperextension are associated with poor outcomes [9–12], and that flexion contractures continued to improve up to two to three years after surgery [9,13]. However, in UC TKA, the correlation between outcomes and postoperative extension angle, and the natural history of the extension angle following surgery have not been well documented.

Determining the postoperative extension angle is one of the most important issues when performing TKA. Reported predictive factors for postoperative extension angle include: pre-operative extension angle, sex, advanced age, femoral posterior condylar offset change, and tibial slope change in PS TKA [9,11,12]. However, it is unclear whether UC TKA has the same predictive factors.

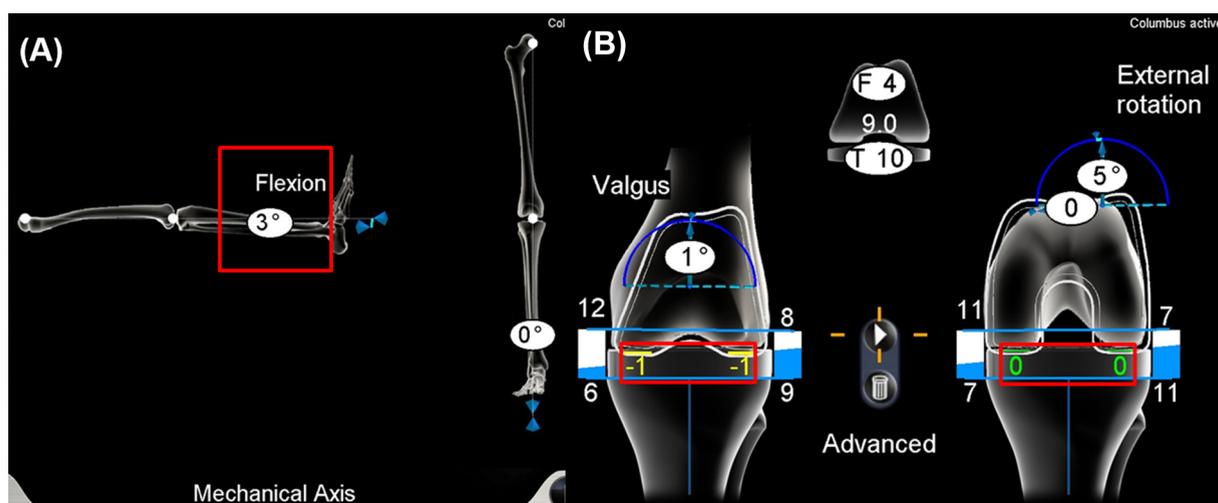
Therefore, the purpose of this study was to investigate the time-dependent changes in extension after TKA using UC inserts and to evaluate the factors that were correlated with the postoperative extension angle. It was hypothesized that the knee tends to gradually extend, and that the pre-operative extension angle is correlated with the postoperative extension angle.

## 2. Materials and methods

This was a retrospective study of 431 patients who underwent image-free navigation-assisted TKA using UC inserts between November 2010 and December 2014 (522 cases). The following were excluded: 21 cases who underwent TKA using an improper gap-balanced navigation system (mediolateral and flexion-extension gap difference of  $\geq 3$  mm); 15 with  $>10^\circ$  flexion contracture or any hyperextension on final assessment with a navigation system (Figure 1); 59 whose pre-operative radiographs or clinical scores were unavailable or inadequate; and 39 with a follow-up period  $<36$  months. Finally, the study population consisted of 331 patients (33 men and 298 women; 388 TKAs), with 57 patients (114 knees) who underwent bilateral TKA using the same type of prosthesis on both sides. The demographic data are briefly summarized in Table 1. This study protocol was approved by the Institutional Review Board (SMC 2018-03-028).

### 2.1. Surgical technique

All surgeries were performed by the senior author using an image-free computer navigation system (Orthopilot; B. Braun Aesculap, Tuttlingen, Germany) that performs kinematic analysis of the hip, knee, and ankle joints. An UC-type Columbus prosthesis (B. Braun, Aesculap, Tuttlingen, Germany) was implanted.



**Figure 1.** Data from the navigation archives. (A) After implantation, final coronal and sagittal alignments were checked. The number displayed in the red box was considered as postoperative sagittal alignment from navigation. (B) Flexion/extension and medial/lateral gaps were displayed just before femoral posterior condylar resection; therefore, mediolateral extension (lateral minus medial), mediolateral flexion (lateral minus medial), medial flexion-extension (flexion minus extension), and lateral flexion-extension (flexion minus extension) gap difference could be calculated.

**Table 1**Basic patient data.<sup>a</sup>

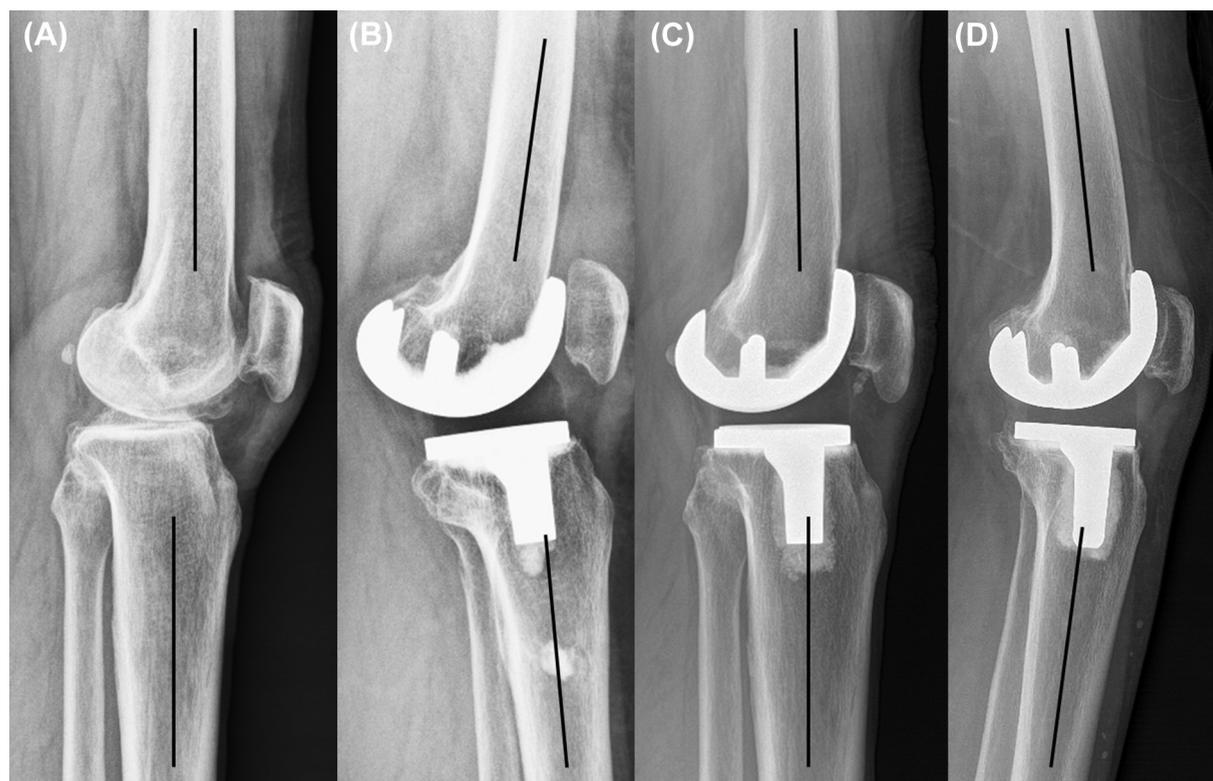
<i>Demographic data</i>	
Sex, male: female	41: 347
Age, years	65.8 ± 6.5 (43 to 91)
Body mass index, kg/m <sup>2</sup>	27.4 ± 3.5 (20 to 45.4)
Number of posterior capsular release, n (%)	43 (11.1%)
Follow up period, months	56.2 ± 16.9 (36 to 85.3)
<i>Navigation data</i>	
Postoperative sagittal alignment, <sup>ob</sup>	−3.7 ± 2.1 (0 to 9)
Mediolateral extension gap difference, mm	1.0 ± 1.0 (−2 to 2)
Mediolateral flexion gap difference, mm	0.8 ± 1.0 (−2 to 2)
Medial flexion-extension gap difference, mm	1.5 ± 0.9 (−2 to 2)
Lateral flexion-extension gap difference, mm	1.4 ± 1.0 (−2 to 2)
<i>Radiographic data<sup>c</sup></i>	
Pre-operative extension angle, °	−5.1 ± 5.7 (−15.7 to 31.9)
Postoperative 5 days extension angle, °	−9.2 ± 4.1 (−26 to 1.1)
Postoperative 6 months extension angle, °	−2.6 ± 5.2 (−19 to 14.5)
Postoperative 1-year extension angle, °	0.6 ± 5.4 (−16.3 to 22.3)
Postoperative 2-years extension angle, °	1.0 ± 5.5 (−16 to 23)
Final follow-up extension angle, °	1.0 ± 5.5 (−17 to 23.5)

<sup>a</sup> Values are expressed as means ± standard deviations (range), unless otherwise indicated.

<sup>b</sup> Obtained from the navigation archives, positive value indicates hyperextension.

<sup>c</sup> Measured with full extension lateral radiographs, positive value indicates hyperextension.

A medial parapatellar approach was used for arthroscopy. After the registration process, both cruciate ligaments were removed from their femoral and tibial attachment sites. Osteophytes, including the posterior side, were also removed. Proximal tibial cutting was performed in a plane perpendicular to the mechanical axis of the tibia. The cutting slope was determined by considering the natural slope: the general target slope was 87°. A slide ruler with a laminar spreader was used to identify the medial and lateral gaps at 90° flexion and extension. Femoral planning – including that for the component size, rotation, and amount of



**Figure 2.** The extension angle was defined as the sagittal diaphyseal axis angle. The *black line* indicates both the femoral and tibial sagittal diaphyseal axes. (A) Indicates pre-operative extension angle, and (B)–(D) indicate postoperative extension angles. (B) Extension angle 15°, (C) Extension angle −1° and (D) Extension angle −11°.

posterior bone cutting – was performed simultaneously to achieve a balanced gap. Acceptable gap balancing was considered when the difference between the lateral extension/flexion gap and medial extension/flexion gap was  $\leq 2$  mm. Mediolateral and flexion-extension gap differences were obtained from navigation archives (Figure 1). Femoral bone cutting and trial insertion were conducted. A sequential posterior capsular release was performed when the patients without pre-operative hyperextension had flexion contractures  $>5^\circ$  despite removal of posterior osteophytes: first, capsular release around the intercondylar notch, then subperiosteal elevation of the capsule from the posterior femoral condyles if needed [14,15].

Implantation was then conducted. Patellar resurfacing was not performed. After implantation, postoperative sagittal alignment from navigation was achieved (a positive value indicated hyperextension, while a negative value indicated a flexion contracture) [16]. The target sagittal alignment from navigation varied from  $-10^\circ$  (flexion contracture  $10^\circ$ ) to  $0^\circ$  based on pre-operative values. A  $<5^\circ$  postoperative flexion contracture was allowed in patients with pre-operative neutral or flexion contractures. An intentional five to  $10^\circ$  flexion contracture was allowed to remain in patients with pre-operative hyperextension [17,18].

The day after surgery, patients were started on isometric quadriceps, active ankle, and straight leg-raising exercises. Two days after surgery, patients commenced knee flexion from 0 to  $120^\circ$ . No patients needed manipulation under anesthesia.

## 2.2. Radiographic and clinical assessments

Radiographic evaluations, including whole-leg radiography with the patella oriented in a forward-facing position and full-extension lateral radiography, were routinely performed before surgery, and at postoperative five days, six months, one year, and two years, and annually thereafter. For the full-extension lateral view, the angle between the distal femoral axis and proximal tibial diaphyseal axis (i.e., the line connecting the midpoints of the outer cortical diameter at five centimeters and 15 cm proximal or distal to the joint line) was defined as the extension angle, and was measured both pre-operatively and postoperatively



**Figure 3.** The posterior condylar offset is defined as the distance from the posterior cortical margin of the femur to the posterior condylar articulation. The dotted line indicates the (A) pre-operative and (B) postoperative posterior condylar offset. Posterior condylar offset change is the difference in this variable between pre-operative and postoperative measurements.

(Figure 2) [9,19–21]. This method has high reproducibility and is more accurate than using a goniometer [12]. A positive value indicated hyperextension, while a negative value indicated a flexion contracture. Time-dependent extension angle changes were investigated from postoperative five days to final follow-up in all patients.

The femoral posterior condylar offset and posterior tibial slope were also obtained from the full-extension lateral view. The femoral posterior condylar offset change was defined as the change in the pre-operative and postoperative distance from the posterior cortical margin to the posterior condyle (Figure 3) [22]. The pre-operative and postoperative hip–knee–ankle (HKA) alignments presented mechanical axis deviation between the femur and the tibia using whole-leg radiography [23]. A positive value indicated a varus deformity. The variables described earlier were all measured to the nearest 0.1° using a picture archiving and communication system (Centricity; General Electric, Chicago, IL, USA). To verify interobserver reliability, the radiographs were evaluated by two independent orthopedic surgeons (YIL and DUK) specializing in knee arthroplasty and who did not participate in the current study. Intraobserver reliability was checked by the observers repeating the same measurements six weeks later.

The knee flexion angle was measured with a goniometer, and the Western Ontario and McMaster Universities Osteoarthritis (WOMAC) index, Knee Society knee score (KSKS), and Knee Society function score (KSFS) were assessed pre-operatively and at final follow-up [24,25]. All radiographic and clinical assessments were compared between pre-operative and final follow-up.

### 2.3. Statistical analysis

The intraclass correlation coefficient was used to quantify both interobserver and intraobserver reliabilities for radiographic assessment. To compare pre-operative and postoperative outcomes, paired *t*-test was used. The time-dependent extension angle changes were analyzed using repeated-measures analysis of variance (ANOVA), and post-hoc comparisons between the mean extension angles of all pairs of points in time were performed; Bonferroni adjustments were applied to the *P*-values to account for multiple testing. Stepwise multiple regression analysis was performed to identify which of the following factors were correlated with the postoperative extension angle: age, sex, body mass index (BMI), whether a posterior capsular release was performed, pre-operative radiographic measurements, postoperative radiographic measurements, and navigation measurements (postoperative sagittal alignment, mediolateral extension gap difference, mediolateral flexion gap difference, medial flexion-extension gap difference, and lateral flexion-extension gap difference).

To investigate the correlation between postoperative extension angle and clinical outcomes, a locally weighted scatterplot smoothing (LOESS) method was used. Pearson correlation analysis between the absolute value of postoperative extension angle and clinical outcomes was also performed to assess the correlation amount of the extension angle from the neutral angle (0°) with clinical outcomes.

A *P*-value <0.05 was considered statistically significant. All data were analyzed using the SPSS software version 20.0 (Chicago, IL, USA). A post hoc power analysis was performed. The primary outcome measure for this study was the difference in mean extension angle during follow-up, which was calculated with repeated-measures ANOVA. It had a power of 99%, with an alpha value of 0.05 to detect any significant difference.

## 3. Results

Mean follow-up duration was 46.2 months and 43 knees (11.1%) had a posterior capsular release. The interobserver and intraobserver extension angle measurements showed good reliability (Table 2). Other interobserver and intraobserver ICCs also showed good agreement regarding radiographic measurement reliability (>0.80). The extension angle was significantly greater and all clinical outcomes were significantly improved after surgery. Postoperative femoral posterior offset and tibial slope were greater than pre-operative measurements (Table 3).

The postoperative extension angle significantly increased from five days to six months ( $P < 0.001$ ), from six months to one year ( $P < 0.001$ ), and from one year to two years ( $P < 0.001$ ), but not from two years to the final follow-up ( $P = 0.851$ ) (mean angles at five days/six months/one year/two years/final follow-up:  $-9.2^\circ/-2.6^\circ/0.6^\circ/1.0^\circ/1.0^\circ$ , respectively) (Figure 4).

Multiple regression analysis was performed to determine which factors were correlated with the postoperative extension angle. Among potential predictive factors, sex and pre-operative extension angle were determined to be significant ( $R^2 = 0.125$ , adjusted  $R^2 = 0.120$ ). A smaller postoperative extension angle was predicted by male sex and smaller pre-operative extension angle (Table 4).

**Table 2**

Intraclass correlation coefficient of interobserver and intraobserver errors in assessing extension angle.

Extension angle	Interobserver	Intraobserver	
		1	2
Pre-operative	0.852	0.867	0.923
Postoperative 5 days	0.812	0.832	0.879
Postoperative 6 months	0.889	0.864	0.801
Postoperative 1 year	0.891	0.884	0.832
Postoperative 2 years	0.931	0.956	0.932
Final follow-up	0.864	0.901	0.853

**Table 3**  
Radiographic and clinical outcomes of pre-operation and final follow-up.<sup>a</sup>

	Pre-operation	Final follow-up	<i>P</i>
Extension angle (°)	−5.1 ± 5.7 (−31.9 to 15.7)	1.0 ± 5.5 (−16.3 to 23)	<0.001
HKA alignment (°)	9.9 ± 5.5 (−8.5 to 25)	0.9 ± 1.8 (−5.5 to 9.1)	<0.001
Femoral posterior offset (mm)	27.8 ± 3.1 (21.6 to 37.8)	30.4 ± 2.8 (23.5 to 40)	<0.001
Tibial slope (°)	80.1 ± 3.6 (68.8 to 88.6)	86.2 ± 2.0 (75.7 to 89.9)	<0.001
WOMAC	55.6 ± 16.5 (9 to 95)	7.1 ± 6.3 (0 to 37)	<0.001
KSKS	52.8 ± 13.2 (3 to 90)	89.9 ± 7.7 (61 to 100)	<0.001
KSFS	52.9 ± 15.7 (10 to 95)	80.3 ± 16.1 (40 to 100)	<0.001
Flexion angle (°)	113.2 ± 16.9 (40 to 141)	125.7 ± 12.5 (55 to 140)	<0.001

HKA = hip-knee-ankle; WOMAC = Western Ontario and McMaster Universities Osteoarthritis index; KSKS = Knee Society knee score; KSFS = Knee Society Function Score.

<sup>a</sup> Values are expressed as means ± standard deviations (range).

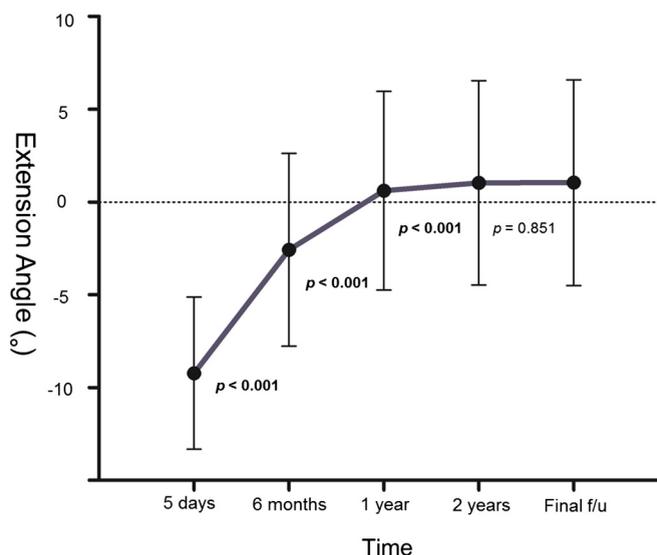
Regarding the correlation between postoperative extension angle and clinical outcomes, less KSKS and KSFS were shown in patients with severe hyperextension or flexion contracture in the LOESS curve. A higher absolute value of extension angle (amount from 0°) was significantly correlated with poor KSKS ( $r = -0.184$ ,  $P < 0.001$ ) and KSFS ( $r = -0.174$ ,  $P < 0.001$ ) (Figure 5).

#### 4. Discussion

The most important finding of this study was that the knee gradually extended until two years after TKA using UC inserts. Sex and pre-operative extension angle were predictive factors for postoperative extension angle. Male sex and pre-operative flexion contracture correlated with postoperative flexion contracture, and female sex and pre-operative recurvatum deformity correlated with postoperative recurvatum deformity.

Pre-operative femoral posterior offset was significantly less than the postoperative measurement; however, the pre-operative measurement did not consider cartilage thickness [26], therefore, the real femoral posterior offset change could be different to this result.

Postoperative ROM is closely related to patient satisfaction after TKA [8]. Obtaining a proper extension angle (avoiding recurvatum or flexion contracture) is as important as achieving an adequate flexion angle. However, time-dependent extension angle changes after TKA have not been adequately investigated. Kim et al. [9] first investigated time-dependent extension



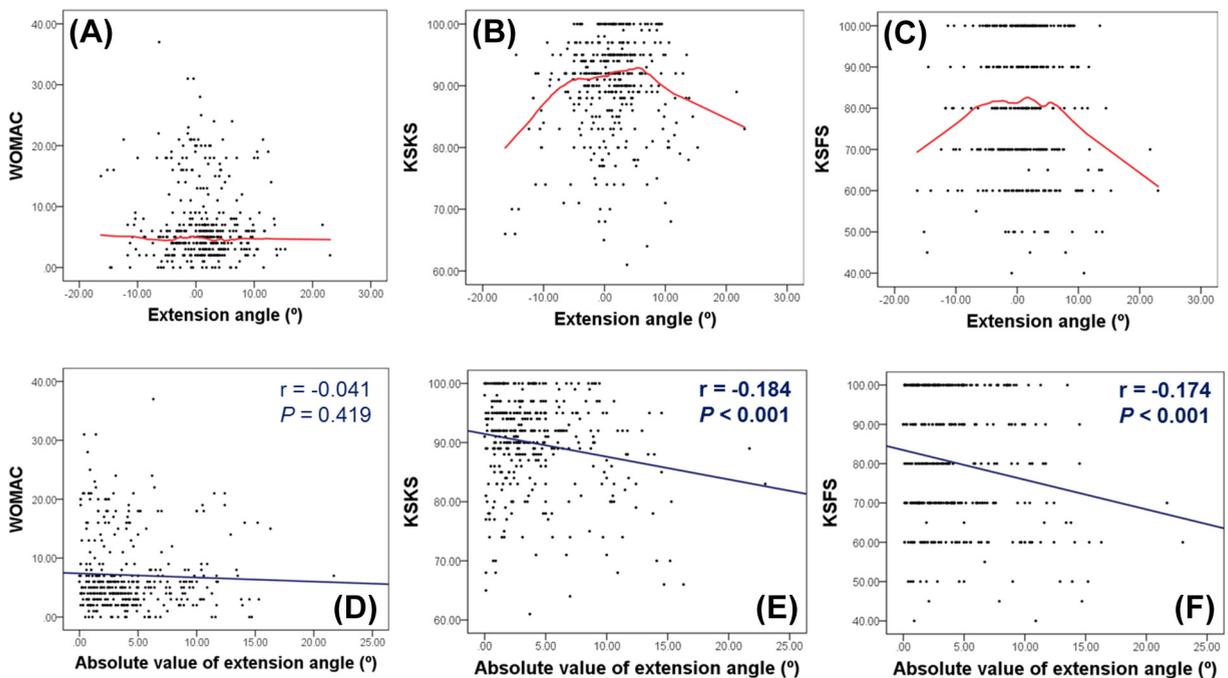
**Figure 4.** Time-dependent extension angle change in all patients. The *P*-value indicates significance between previous and subsequent periods.

**Table 4**  
Multiple regression analysis of factors correlated with postoperative extension angle.

Dependent variable	Independent variables	Non-standardized Coefficients		Standardized Coefficients	P
		B	SE	B	
Postoperative extension angle	Age	−0.086	0.043		0.074
	<b>Sex</b>	<b>2.727</b>	<b>0.872</b>	<b>0.15</b>	<b>0.002</b>
	BMI	0.052	0.081		0.285
	Posterior capsular release	−0.048	0.09		0.319
	<b>Pre-operative extension angle</b>	<b>0.302</b>	<b>0.047</b>	<b>0.31</b>	<b>&lt;0.001</b>
	Pre-operative HKA alignment	0.049	0.055		0.305
	Pre-operative tibial slope	0.006	0.083		0.9
	Pre-operative flexion angle	−0.055	0.019		0.28
	Postoperative HKA alignment	0.022	0.16		0.646
	Postoperative tibial slope	0.043	0.137		0.373
	Postoperative flexion angle	0.001	0.024		0.976
	Femoral posterior condylar offset change	−0.029	0.092		0.744
	Tibial slope change	−0.022	0.009		0.645
	Immediate postoperative sagittal alignment	0.058	0.134		0.061
	Mediolateral extension gap difference	0.076	0.032		0.112
	Mediolateral flexion gap difference	0.042	0.033		0.384
Medial flexion-extension gap difference	−0.024	0.048		0.621	
Lateral flexion-extension gap difference	−0.045	0.043		0.35	

HKA = hip-knee-ankle; B = unstandardized coefficients; SE = standard error;  $\beta$  = standardized coefficients; BMI = body mass index. Boldface text indicates factors that significantly affected postoperative extension angle.

angle changes in PS TKA. They reported that patients with immediate postoperative flexion contractures tended to improve, while patients with  $<5^\circ$  flexion contractures or any immediate postoperative hyperextension tended to maintain the extension angle. In the current study, the postoperative extension angle tended to decrease until two years post-operation. These findings suggest that knees having UC TKA can be more extended until two years compared with the intraoperative extension angle. In future, a comparative study of the extension angle using other bearing designs is needed to determine any differences in the pattern of time-dependent change. The greatest reduction was observed from five days to six months post operation Radiographic measurements (mean angle  $9.2^\circ$ ) at postoperative five days were greater than navigation measurements (mean angle  $3.9^\circ$ ). A previous study demonstrated that immediate postoperative radiographic findings cannot fully reflect intraoperative navigation findings



**Figure 5.** (A)–(C) Locally weighted scatter plot smoothing (LOESS) curves of the clinical outcomes according to the postoperative extension angle: Western Ontario and McMaster Universities Osteoarthritis index, Knee Society Knee Score (KSKS) and Knee Society Function Score (KSFS). (D)–(F) Pearson correlation analysis between the absolute value of postoperative extension angle and clinical outcomes.

because of inability to bear full weight [27]; therefore, caution is required when interpreting the extension angle at postoperative five days.

Previous studies have reported that male sex, older age, greater pre-operative flexion contracture, increment of posterior tibial slope, and increment of femoral condylar offset were predictive factors for postoperative flexion contractures [9,11,12,22,28]. Therefore, the finding that sex and pre-operative extension angle were predictive factors for postoperative extension angle was not surprising; however, this is an important finding for clinical application. Special consideration may be needed when performing TKA using a UC insert in female patients and/or those with pre-operative knee hyperextension deformity, even if a successful extension angle was obtained at surgery.

It is generally accepted that a remaining flexion contracture leads to poor outcome after TKA. Interestingly, few studies have investigated correlations between postoperative hyperextension and clinical outcomes after TKA [9,10]. Siddiqui et al. [10] divided postoperative recurvatum measurements as 0 to five degrees, five to 10°, and >10° in CR and PS TKA. They demonstrated that a recurvatum deformity >5° was correlated with poor clinical outcomes. Kim et al. did not separate patient groups with hyperextension in PS TKA, and demonstrated that patients with hyperextension showed inferior clinical outcomes [9]. The current results showed that severe hyperextension or flexion contracture was related to inferior KSKS and KSFS in patients who had TKA with a UC insert, which was similar to PS or CR type TKA.

This study had several limitations. First, the procedures of cementing and implantation could have affected the flexion-extension or medial-lateral gap; therefore, there is a possibility that the actual final gap can differ with the obtained gap from navigation archives. However, the surgeries were performed by a single experienced surgeon with the same procedures; therefore, the difference should have been minimal. Second, the target extension angle varied (−10° to 0°) based on pre-operative extension angle; 0° was targeted for patients with pre-operative flexion contracture and −10° to −5° for pre-operative hyperextension. It is inevitable that the pre-operative deformity is fixed; however, it can be a major bias to the postoperative extension angle. Third, the follow-up period was relatively short. Further studies are needed to evaluate implant survival and long-term change in the extension angle. Fourth, there could be ethnic differences in laxity or stiffness after TKA; therefore, investigations in different races are needed.

## 5. Conclusion

Following UC TKA, knees gradually extended until two years post operation. Sex and pre-operative extension angle were predictive factors for the postoperative extension angle in TKA using UC inserts.

## Ethical statement

This article does not contain any studies with human participants or animals performed by any of the authors. The protocol used to evaluate radiographic findings and intraoperative navigation data was approved by our institution's investigational review board. (SMC2018-03-028).

## Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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