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Predictors of flexion contracture progression following total knee arthroplasty: role of global sagittal alignment and patient age

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Abstract

Background Knee flexion contracture (KFC) progression after total knee arthroplasty (TKA) can significantly affect functional outcomes through disruption of the biomechanical knee–hip–spine kinetic chain. This study was conducted to investigate whether preoperative global sagittal alignment parameters, particularly the center of the acoustic meatus-sagittal vertical axis (CAM-SVA), could predict short-term KFC progression after TKA.

Methods A retrospective case–control study was performed on 760 consecutive TKA cases, with 347 knees meeting inclusion criteria. KFC progression was defined as > 5° increase in knee flexion angle between immediate postoperative and final follow-up radiographs. Demographic factors and radiographic parameters were analyzed using univariate and multivariate logistic regressions. Patient-reported outcomes were assessed using the American Knee Society Score (AKSS) and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Potential sources of bias were addressed through standardized measurement protocols and inter-observer reliability testing.

Results KFC progression was observed in 39 knees (11.2%), with mean progression of 8.0 ± 3.8° over 23.5 ± 13.1 months. Multivariate analysis revealed that CAM-SVA and age were independently associated with KFC progression (odds ratio: 1.02 [95% CI 1.01–1.04], $p < 0.05$; and 1.09 [95% CI 1.02–1.17], $p < 0.01$, respectively). At 12 months, the KFC progression group demonstrated significantly lower AKSS scores and higher WOMAC scores ($p < 0.05$) as compared to the nonprogression group.

Conclusions CAM-SVA and advanced age were identified as independent predictors of KFC progression following TKA, supporting the hypothesis that global sagittal malalignment contributes to compensatory knee flexion through biomechanical interdependence of the knee–hip–spine kinetic chain. Assessment of preoperative global sagittal alignment may help identify patients at risk for KFC progression and inform individualized treatment strategies.

Keywords Knee flexion contracture, Total knee arthroplasty, Global sagittal alignment, Spinopelvic alignment, Sagittal vertical axis

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Background

Total knee arthroplasty (TKA) represents the gold-standard surgical procedure for end-stage knee osteoarthritis, with the primary objectives of improving pain, function, and overall quality of life [1–3]. However, postoperative knee flexion contracture (KFC), defined as the inability to fully extend the knee, remains a significant complication that can limit functional recovery [4]. Despite established intraoperative surgical techniques to address KFC and achieve improved postoperative range of motion (ROM), progressive KFC after TKA continues to compromise normal gait patterns, reduce overall mobility, and diminish patient satisfaction [5].

The biomechanical relationship between the spine, pelvis, hip, and knee joints has gained increasing recognition in recent literature, particularly regarding the concept of the "knee–spine syndrome" [6–8]. This syndrome describes the compensatory mechanisms whereby alterations in one segment of the kinetic chain induce adaptive changes in adjacent segments to maintain global balance [9, 10]. Specifically, patients with chronic knee flexion contracture often exhibit compensatory reduced lumbar lordosis (LL) and anterior pelvic tilt (PT) adaptations [6]. Conversely, spinal sagittal imbalance, such as flatback deformity, force the hips and knees into compensatory flexion postures to maintain an upright stance and horizontal gaze [7, 9, 11].

The biomechanical interdependence of these structures operates through several mechanisms. First, the gravity line principle dictates that the body's center of mass must remain within the base of support for stability [12]. When spinal sagittal imbalance shifts the gravity line anteriorly, compensatory knee flexion becomes necessary to prevent forward falling [13]. Second, the muscular tension-length relationships across the kinetic chain become altered, with hip flexors and hamstrings developing adaptive shortening in response to chronic postural changes [14]. Third, proprioceptive feedback mechanisms integrate spinal and lower extremity positioning, creating learned motor patterns that persist even after local correction [15].

Previous investigations have explored spinopelvic parameters' influence on TKA outcomes, with conflicting evidence regarding their predictive value [16–18]. Although some studies identified high pelvic incidence (PI) or PI-LL mismatch as risk factors for poor knee extension outcomes [17, 18], others found that TKA successfully corrected local deformities regardless of global alignment [16]. These discrepancies highlight the need for comprehensive assessment of global sagittal balance parameters beyond traditional spinopelvic measurements.

Based on the biomechanical evidence supporting the interconnected nature of the knee–hip–spine kinetic chain and preliminary observations of compensatory mechanisms in sagittal plane deformities, it was hypothesized that patients with greater preoperative global sagittal malalignment, as measured by the center of the acoustic meatus-sagittal vertical axis (CAM-SVA), would demonstrate increased risk of KFC progression following TKA due to persistent compensatory biomechanical demands. This study was therefore conducted to investigate potential risk factors for postoperative KFC progression, including global sagittal alignment parameters measured by biplanar low-dose X-ray, spinopelvic alignment parameters, and demographic characteristics.

Methods

Study design and setting

A retrospective case–control study was conducted following approval from the Institutional Review Board of our hospital (9-2025-0043). The study adhered to STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for observational research [19]. The data were collected from patients who underwent primary TKA at a single tertiary referral hospital between June 2019 and March 2022. All surgical procedures were performed in the same operating facility with standardized perioperative protocols.

Participants and sample size calculation

From 760 consecutive knees that underwent primary TKA, 347 knees (308 patients) were included in the final analysis (Fig. 1). Inclusion criteria comprised availability of preoperative biplanar low-dose X-ray evaluation for global sagittal alignment assessment, a minimum of 6 months of clinical and radiographic follow-up, and complete preoperative and postoperative standard radiographic assessments. Patients were excluded if they had undergone revision TKA procedures, had underlying inflammatory joint disease such as rheumatoid arthritis, presented with active infection, had incomplete imaging data, reported a history of major lower-extremity trauma, or had neurological disorders affecting gait or posture. Exclusions included: revision procedures (n = 36), inflammatory arthritis (n = 16), active infection (n = 3), incomplete imaging (n = 260), inadequate follow-up (n = 65), history of major lower-extremity trauma (n = 13), and neurological disorders affecting gait or posture (n = 20). Power analysis was performed based on the preliminary data from pilot studies [20]. The calculation indicated that a minimum of 298 knees would be required to detect a clinically relevant difference in CAM-SVA between groups with and without KFC progression (effect size = 0.35, $\alpha = 0.05$, power = 0.8).

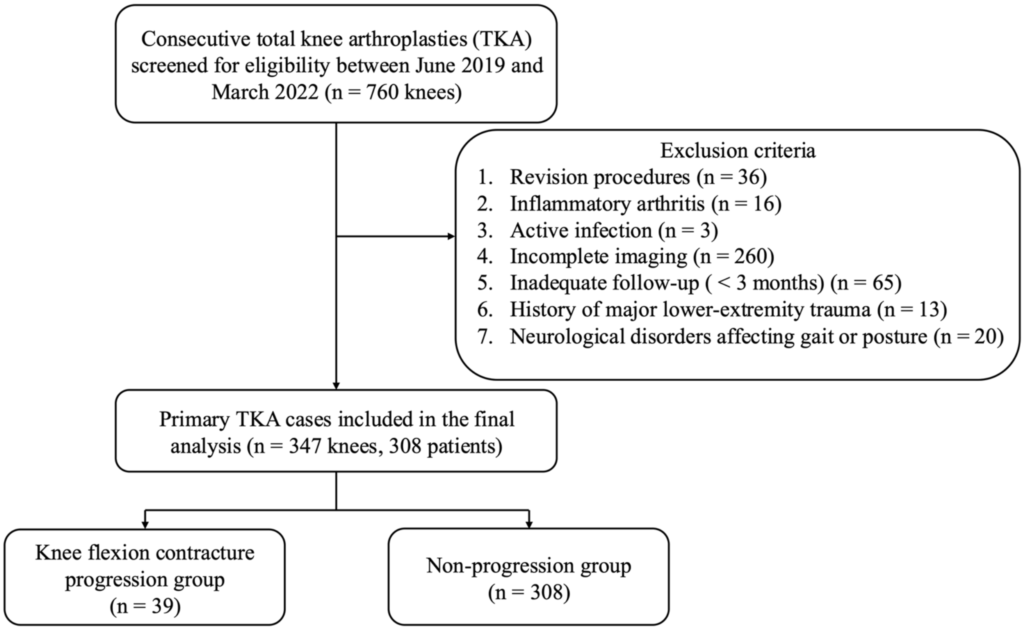

Fig. 1 Flow diagram of study participants according to STROBE guidelines

Variables

The primary outcome was KFC progression, defined as an increase of more than 5° in the flexion angle at final follow-up when compared with immediate postoperative radiographs. This threshold was selected based on the previous literature indicating clinical significance [21]. Global sagittal alignment parameters assessed as exposure variables included the CAM-SVA (horizontal distance from CAM plumb line to posterior superior corner of the first sacral vertebral body [S1]), SVA (horizontal distance from C7 plumb line to posterior superior corner of S1), spinopelvic parameters including PI, PT, and sacral slope (SS), standing knee flexion angle, anterior pelvic tilt angle (APTA) and sagittal pelvic rotation status [22] (Fig. 2). Age, sex, body mass index (BMI), preoperative ROM, presence of preoperative KFC (≥ 10°), and limitation of motion (< 100° flexion) were assessed as potential confounding variables.

Data sources and measurement

All radiographic measurements were performed using standardized protocols. KFC was measured on lateral knee radiographs obtained in the supine position immediately postoperatively (within 1 week of surgery) and in the standing position preoperatively and at the final follow-up (minimum 6 months postoperatively), using an biplanar low-dose X-ray imaging (EOS Imaging S.A., Paris, France) [23]. Global sagittal alignment was assessed with biplanar low-dose X-ray imaging performed with patients in a standardized standing position, arms crossed at chest level, and looking straight ahead [24], with parameters measured according to established protocols [25, 26]. For the APTA measurements, an anterior pelvic tilt was defined as a positive value, and a posterior pelvic tilt as a negative value. Based on the sagittal pelvic rotation status, we classified patients into three groups: normal (−15° to 0°), retroversion (< −15°), and anteversion (> 0°) [25]. Two experienced orthopedic surgeons independently performed all measurements, and when discrepancies exceeded 3°, consensus was reached through discussion or with the involvement of a third observer. Inter-observer reliability was evaluated by calculating intraclass correlation coefficients.

Clinical assessment

Clinical evaluations were conducted preoperatively and 3, 6, and 12 months postoperatively. We used the American Knee Society Score (AKSS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) as patient-reported outcome measures (PROMs). In addition, objective clinical parameters, including active and passive ROM, were measured using a standard goniometer in the preoperative period and at each follow-up visit.

Surgical technique and perioperative management

All TKA procedures were performed by one experienced arthroplasty surgeon (W.S.L) using a standard medial parapatellar approach. All patients received

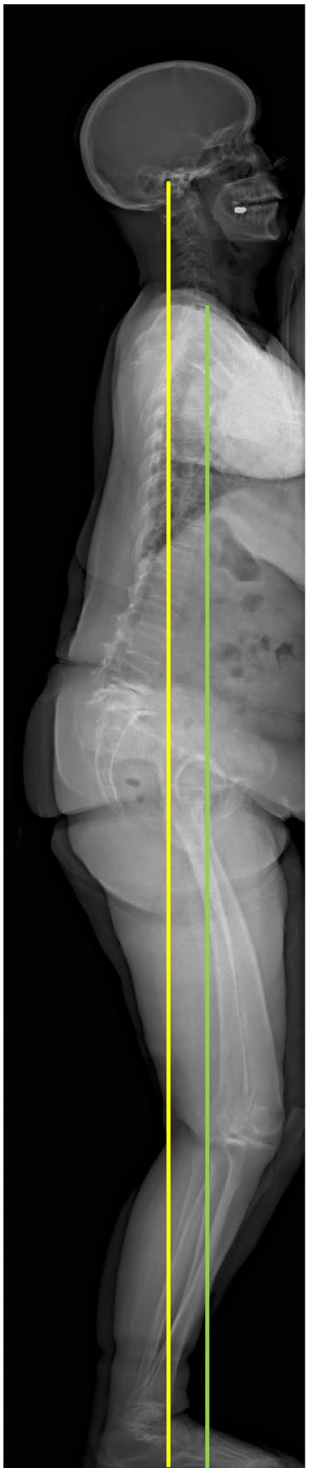

Fig. 2 Radiographic assessment of global sagittal alignment on standing biplanar low-dose X-ray imaging. Yellow line: center of the acoustic meatus-sagittal vertical axis; Green line: sagittal vertical axis

posterior-stabilized implants (Persona, Zimmer Biomet, Warsaw, IN, USA) with cement fixation. The distal femoral cut was made perpendicular to the mechanical axis with 5°–7° of valgus relative to the anatomical axis, and the proximal tibial cut was performed perpendicular to the mechanical axis of the tibia. Standard soft-tissue release and balancing techniques were used to achieve equal flexion and extension gaps. Patellar resurfacing was performed selectively depending on the patient's cartilage condition and alignment. Postoperative management followed a standardized rehabilitation protocol, which included isometric quadriceps exercises beginning on postoperative day one, continuous passive motion therapy, and progressive weight-bearing as tolerated with a walker or crutches. Most patients were discharged to home or a rehabilitation center by postoperative day 3 to 5, depending on clinical progress. Full weight-bearing without assistance was typically achieved by 2–3 weeks postoperatively, and ROM exercises were continued for at least 2 months.

Statistical analysis

Descriptive statistics were calculated for all variables and are expressed as the mean ± standard deviation for continuous data and frequencies with percentages for categorical data. The Shapiro–Wilk test was used to evaluate the normality of each data distribution. Comparisons between knees with and without KFC progression were performed using independent t tests or Mann–Whitney U tests for continuous variables and chi-square or Fisher's exact tests for categorical variables, as appropriate. Variables achieving a p value < 0.1 in univariate analysis were entered into a multivariate logistic regression model to identify independent predictors of KFC progression. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. For PROMs, a linear mixed-effects model was used to analyze repeated measurements over time, with adjustment for relevant covariates (age, sex, and baseline scores). All statistical analyses were conducted using R software, version 4.4.0, with significance set at $p < 0.05$.

Results

Participants and descriptive data

A total of 347 knees (308 patients) were analyzed. Baseline characteristics are presented in Table 1. The study population had a mean age of 72.3 ± 5.9 years with 89.0% female predominance. Mean BMI was 26.0 ± 1.1 kg/m^2. Preoperative KFC (≥ 10°) was present in 64 knees (18.4%), and limitation of motion (< 100° flexion) in 48 knees (13.8%).

Table 1 Comparison of Clinical and Radiographic Parameters Between the Progression and Nonprogression Knee Flexion Contracture Groups

	KFC progression group	KFC nonprogression group	Total	*p*
n (knees)	39	308	347	
Age (years)	76.4 ± 5.1	71.8 ± 5.8	72.3 ± 5.9	< 0.01
Female (n [%])	35 (89.7)	274 (89.0)	309 (89.0)	1.00
Body mass index (kg/m^2)	26.1 ± 1.2	26.0 ± 1.1	26.0 ± 1.1	0.49
Operated side (Rt/Lt) (n [%])	17/22	165/143	182/165	0.32
Preoperative knee ROM				
Total angle	119.1 ± 15.3	125.0 ± 13.6	124.3 ± 13.9	< 0.05
Flexion contracture	10.8 ± 7.6	6.2 ± 7.3	6.7 ± 7.4	< 0.01
Further flexion	108.3 ± 18.5	118.8 ± 18.0	117.6 ± 18.4	< 0.01
Preoperative KFC (n [%])	14 (35.9)	50 (16.2)	64 (18.4)	< 0.01
Preoperative LOM (n [%])	8 (20.5)	40 (13.0)	48 (13.8)	0.30
CAM-SVA, mm	51.3 ± 63.8	7.2 ± 43.9	12.1 ± 48.5	< 0.01
SVA, mm	74.4 ± 49.5	36.0 ± 41.1	40.3 ± 43.7	< 0.01
Standing knee flexion angle, °	16.4 ± 7.5	11.0 ± 7.4	11.6 ± 7.6	< 0.01
Pelvic incidence, °	57.6 ± 11.1	57.4 ± 11.8	57.4 ± 11.7	0.90
Pelvic tilt, °	24.6 ± 9.7	22.0 ± 9.6	22.3 ± 9.7	0.11
Sacral slope, °	33.0 ± 11.7	35.4 ± 10.3	35.1 ± 10.5	0.18
Anterior pelvic tilt angle, °	− 11.3 ± 9.1	− 8.8 ± 8.0	− 9.1 ± 8.2	0.07
Sagittal pelvic rotation status, (n [%])				0.48
Anteversion	4 (10.3)	42 (13.6)	46 (13.3)	
Neutral	24 (61.5)	204 (66.2)	228 (65.7)	
Retroversion	11 (28.2)	62 (20.1)	73 (21.0)	

KFC knee flexion contracture, *Rt* right, *Lt* left, *ROM* range of motion, *LOM* limitation of motion, *CAM-SVA* center of the acoustic meatus–sagittal vertical axis

Outcome data

KFC progression was observed in 39 knees (11.2%) over a mean follow-up period of 23.5 ± 13.1 months. Compared with the nonprogression group, patients in the progression group were older (76.4 ± 5.1 vs. 71.8 ± 5.8 years, p < 0.01), had a lower preoperative total range of motion (119.1 ± 15.3 vs. 125.0 ± 13.6°, p < 0.05), and showed a higher prevalence of preoperative KFC (35.9% vs. 16.2%, p < 0.01). The mean degree of progression was 8.0 ± 3.8° from the immediate postoperative measurements (Table 2).

Main results – sagittal alignment parameters

Patients with KFC progression exhibited significantly altered preoperative global sagittal alignment compared with those without progression, including greater CAM-SVA (51.3 ± 63.8 vs. 7.2 ± 43.9 mm, p < 0.01), greater SVA (74.4 ± 49.5 vs. 36.0 ± 41.1 mm, p < 0.01), and a larger standing knee flexion angle (16.4 ± 7.5 vs. 11.0 ± 7.4°, p < 0.01). No significant differences were found in spinopelvic parameters (PI, PT, SS) or sagittal pelvic rotation status between the two groups.

Table 2 Longitudinal Assessment of the Knee Flexion Angle on Radiographs Throughout the Follow-up Period

	KFC progression group	KFC nonprogression group	Total	*p*
Radiographic flexion contracture angle, °				
Preoperative	14.3 ± 8.1	7.0 ± 7.3	7.8 ± 7.7	< 0.01
Immediate postoperative	3.9 ± 3.6	5.6 ± 3.5	5.4 ± 3.5	< 0.01
Final follow up	11.9 ± 5.3	0.5 ± 4.8	1.8 ± 6.1	< 0.001
Degree of KFC progression	8.0 ± 3.8	− 5.2 ± 5.0	− 3.7 ± 6.4	< 0.001
Follow up duration, months	21.1 ± 11.9	23.8 ± 13.3	23.5 ± 13.1	0.22

KFC, knee flexion contracture

Main results: regression analysis

Univariate analysis identified advanced age, preoperative KFC, increased CAM-SVA, and increased SVA as significant predictors of KFC progression (all p < 0.01). In the multivariate logistic regression model (Table 3), only CAM-SVA (OR, 1.02; 95% CI 1.01–1.04; p < 0.05) and age (OR, 1.09; 95% CI 1.02–1.17; p < 0.01) remained as independent predictors.

Clinical outcomes

Both groups demonstrated significant improvements from baseline; however, at 12 months, the progression group showed inferior clinical outcomes compared with the nonprogression group (Table 4), including lower AKSS knee scores (87.4 ± 5.1 vs. 90.2 ± 4.7, p < 0.05), lower AKSS function scores (75.5 ± 7.2 vs. 78.8 ± 5.7, p < 0.05), and higher WOMAC total scores (22.3 ± 7.4 vs. 18.6 ± 8.1, p < 0.05).

Discussion

This study identified CAM-SVA and age as independent predictors of KFC progression following TKA. Each millimeter increase in CAM-SVA was associated with a 2% increased odds of progression, while each year of age conferred a 9% increased risk. These findings support the hypothesis that global sagittal malalignment contributes to KFC progression through persistent biomechanical compensatory demands on the knee joint.

Table 3 Univariate and Multivariate Logistic Regression Analyses for Predicting Knee Flexion Contracture After Total Knee Arthroplasty

Variables	Univariable		Multivariable	
	OR (95% CI)	*P*	OR (95% CI)	*P*
Age	1.15 (1.08–1.23)	< 0.001	1.09 (1.02–1.17)	< 0.01
Female sex	1.09 (0.36–3.24)	0.88		
Body mass index	1.11 (0.82–1.51)	0.49		
Preoperative knee flexion contracture	**2.89 (1.41–5.94)**	**< 0.01**	1.86 (0.57–6.05)	0.31
Preoperative limitation of motion	1.73 (0.74–4.03)	0.20		
CAM-SVA	**1.02 (1.01–1.02)**	**< 0.001**	**1.02 (1.01–1.04)**	**< 0.05**
SVA	**1.02 (1.01–1.02)**	**< 0.001**	0.98 (0.97–1.01)	0.50
Standing knee flexion angle	**1.09 (1.04–1.13)**	**< 0.001**	1.03 (0.98–1.09)	0.28
Pelvic incidence	1.00 (0.97–1.03)	0.89		
Pelvic tilt	1.03 (0.99–1.06)	0.11		
Anterior pelvic tilt angle	0.96 (0.93–1)	0.07	1.02 (0.83–1.24)	0.86

OR odds ratio, *CI* confidence interval, *CAM-SVA* center of the acoustic meatus–sagittal vertical axis

Table 4 Comparison of Patient-reported Outcome Measures Between the Flexion Contracture Progression and Nonprogression Groups

	KFC progression group	KFC nonprogression group	Total	*p*
AKS Knee Score				
Preoperative	41.2 ± 9.2	45.7 ± 8.1	45.2 ± 8.3	0.16
Postoperative 3 months	82.5 ± 8.2	85.1 ± 7.9	84.7 ± 8.1	0.34
Postoperative 6 months	86.5 ± 6.3	88.3 ± 6.2	88.3 ± 6.1	0.35
Postoperative 1 year	87.4 ± 5.1	90.2 ± 4.7	90.1 ± 4.8	< 0.05
AKS Function Score				
Preoperative	37.3 ± 9.6	42.7 ± 8.7	42.1 ± 8.9	0.12
Postoperative 3 months	73.7 ± 6.8	74.6 ± 6.1	74.5 ± 6.3	0.65
Postoperative 6 months	75.2 ± 7.5	75.3 ± 5.6	75.2 ± 6.2	0.54
Postoperative 1 year	75.5 ± 7.2	78.8 ± 5.7	77.6 ± 6.5	< 0.05
WOMAC				
Preoperative	70.2 ± 13.1	67.8 ± 11.7	68.2 ± 12.1	0.15
Postoperative 3 months	27.2 ± 9.5	25.0 ± 9.3	25.1 ± 9.3	0.25
Postoperative 6 months	25.7 ± 9.1	23.4 ± 8.9	23.6 ± 9.0	0.12
Postoperative 1 year	22.3 ± 7.4	18.6 ± 8.1	18.9 ± 7.8	< 0.05

KFC, knee flexion contracture; AKS, American Knee Society; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index

The relationship between global sagittal alignment and knee flexion operates through multiple interconnected biomechanical pathways (Fig. 3). When spinal deformity shifts the gravity line anteriorly, the body employs a series of compensatory mechanisms to maintain balance [27]. The primary adjustment occurs through pelvic retroversion, which extends the hip joints; however, once pelvic compensation is exhausted, the knees must flex to shift the center of mass posteriorly [28]. This compensatory knee flexion becomes obligatory for maintaining an upright stance and can persist even after local surgical correction, generating sustained flexion moments. Chronic sagittal malalignment also induces adaptive changes in muscle tendon units throughout the kinetic chain [29]. The hip flexors, including the iliopsoas and rectus femoris, develop contractures due to prolonged shortening, while the hamstrings undergo adaptive shortening to support the flexed knee posture. These muscular adaptations increase passive tension that resists full knee extension, even when total knee arthroplasty has addressed the intra-articular pathology [30].

In addition, patients with long-standing sagittal imbalance develop altered motor control patterns that may persist after surgery [31]. The central nervous system adapts to chronic postural deviations by modifying muscle recruitment strategies and proprioceptive feedback loops, creating learned motor programs in which knee flexion becomes the perceived "normal" position [32]. Overcoming these neuroplastic changes often requires prolonged and targeted rehabilitation [33]. The biomechanical environment created by sagittal malalignment influences the knee extension gap through multiple mechanisms [34]. Chronic knee flexion results in posterior capsular contracture and shortening of the collateral ligaments in their flexed position. In addition, the altered force vectors generated by forward trunk lean increase anteriorly directed forces on the tibia, further promoting knee flexion. Over time, quadriceps insufficiency develops due to chronic lengthening in the flexed position, thereby reducing the active capability to generate an extension moment [35].

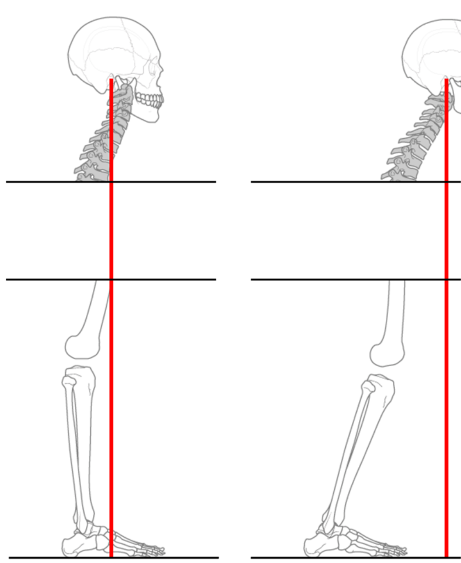

Fig. 3 Biomechanical mechanisms of the knee–hip–spine syndrome and compensatory patterns in sagittal plane malalignment. (Left) Knee flexion contracture nonprogression model with the center of the acoustic meatus plumb line (red line) positioned within the physiologic range. (Right) Knee flexion contracture progression model associated with forward sagittal imbalance requiring compensatory knee flexion

The current findings align with and extend previous research on spinopelvic influences on TKA outcomes. Okamoto et al. reported that high PI ($\geq 55°$) was associated with residual KFC, suggesting that patients requiring greater LL for balance might struggle to achieve full extension [36]. However, the present study's focus on CAM-SVA provides a more comprehensive assessment of global balance rather than isolated pelvic morphology. Vigdorchik et al. found that 82% of patients requiring manipulation for stiffness had significant PI-LL mismatch, supporting the role of spinal deformity in knee dysfunction [18]. The current study extends these findings by demonstrating that global sagittal parameters predict progression rather than just residual contracture.

Conversely, Han et al. reported successful local correction regardless of spinal alignment [16]. This apparent discrepancy may reflect differences in follow-up duration, as compensatory mechanisms might manifest over time rather than immediately postoperatively. The recent biomechanical studies have demonstrated that patients with forward sagittal imbalance exhibit increased knee flexion moments during gait, supporting the mechanical basis for the observed associations [37]. In addition, finite element modeling has shown that altered loading patterns in sagittal malalignment create asymmetric stresses on TKA components, potentially contributing to progressive deformity [38].

These findings have several important implications for clinical practice. Surgeons should consider obtaining global sagittal alignment radiographs in high-risk patients, particularly elderly individuals or those with evident postural abnormalities, as the CAM-SVA measurement provides valuable prognostic information that can inform patient counseling and surgical planning [39]. In patients with significant sagittal imbalance, modifications to the standard surgical technique may be warranted, including more aggressive posterior capsular release, selection of a smaller femoral component to increase the extension gap, and careful adjustment of the tibial slope to avoid inadvertent flexion bias. In severe cases, staged procedures to address spinal deformity before total knee arthroplasty may also be considered. Postoperatively, rehabilitation protocols might be tailored for high-risk patients, emphasizing extension exercises and early mobilization with potentially more frequent monitoring to detect and address early signs of KFC development.

Several limitations should be acknowledged. First, the retrospective design introduces potential selection and information bias despite efforts to standardize data collection. Second, the mean follow-up duration of 23.5 months may not capture late progression patterns or long-term adaptation. Third, the single-surgeon, single-center setting reduces technical variability but limits the generalizability of the findings to other practices and populations. Fourth, although inter-observer reliability was high, radiographic measurements have inherent variability that could affect classification. Fifth, unmeasured confounders such as muscle strength, bone quality, activity level, and comorbidities were not assessed but may have influenced the outcomes. Sixth, the 5° threshold for defining progression, while based on previous literature, remains somewhat arbitrary and may not reflect clinically meaningful changes for all patients. Finally, given the observational design, causal relationships between sagittal alignment and KFC progression cannot be definitively established. Nevertheless, several measures were taken to minimize potential sources of bias, including consecutive sampling with predefined inclusion and exclusion criteria, standardized and blinded measurements, prospective data collection using validated tools, and multivariate adjustment for known confounders.

Conclusions

This study demonstrated that larger preoperative CAM-SVA values and advanced age independently predict KFC progression following TKA. The findings support the biomechanical concept that global sagittal malalignment creates persistent compensatory demands on the knee joint through the interconnected knee–hip–spine kinetic chain. Patients experiencing KFC progression demonstrated inferior clinical outcomes, highlighting the clinical significance of this complication. Recognition of these risk factors enables identification of high-risk patients who may benefit from modified surgical techniques, intensified rehabilitation protocols, and closer postoperative monitoring. Integration of global sagittal alignment assessment into preoperative planning represents an important step toward personalized arthroplasty care and optimized long-term outcomes.

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Author contributions
W.S.L (Woo-Suk Lee): Supervision, Writing – review & editing B.W.C (Byung Woo Cho): Investigation, Project administration, Validation H.M.K (Hyuck Min Kwon): Data curation, Statistical support, Formal analysis T.H.K (Tae Hyung Kim): Data curation, Visualization K.K.P (Kwan Kyu Park): Conceptualization, Methodology, Statistical analysis J.Y.P (Jun Young Park): Conceptualization, Methodology, Supervision, Funding acquisition, Writing – original draft.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was approved by the Institutional Review Board (IRB) of Yongin Severance Hospital (9–2025-0043), and the requirement for informed consent was waived due to the retrospective nature of the study. The study was conducted in accordance with the Declaration of Helsinki.

Consent for publication
Individual consent for publication was waived by the IRB due to the retrospective nature of the study and complete anonymization of all patient data and images.

Competing interests
The authors declare no competing interests.

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