Alterations in Ankle Biomechanics and Alignment Following Unilateral Total Knee Arthroplasty for Valgus Deformity: An Eastern Indian Cohort Study

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Abstract: ***Background**: While Total Knee Arthroplasty (TKA) is highly effective in restoring knee kinematics, its cascading biomechanical effects on the bilateral ankle joints- particularly in the context of valgus knee deformities, which often present late and with significant severity in the Eastern Indian demographic-remain inadequately defined. This study aimed to quantify the impact of unilateral TKA on ipsilateral and contralateral ankle tilt, lower extremity alignment, and compensatory biomechanics in valgus osteoarthritis. **Methods**: A retrospective cohort study was conducted at a tertiary medical college, analyzing 31 consecutive patients who underwent unilateral TKA for end-stage knee osteoarthritis complicated by mild-to-moderate valgus deformity between January 2023 and January 2025. Comprehensive pre- and postoperative standing full-length lower limb radiographs were evaluated. Key radiographic parameters included the hip-knee-ankle angle (HKA), weight-bearing line ratio (WBLR), knee joint line convergence angle (KJLCA), knee joint line obliquity (KJLO), tibial anterior surface angle (TAS), tibial plafond inclination (TPI), talar inclination (TI), and tibiotalar tilt (TT). To assess the impact of surgical correction magnitude, the 31 participants were stratified into three cohorts based on the degree of alignment correction: Cohort I (0°-5°, n=9), Cohort II (5°-10°, n=14), and Cohort III (10°-15°, n=8). Additionally, patients were sub-classified based on the preoperative alignment of the unoperated contralateral knee into varus (n=12) and valgus (n=19) groups. **Results**: Radiographic analysis demonstrated that mechanical axis restoration (HKA change) precipitated simultaneous, statistically significant alterations in both the TAS and TT. The absolute values for postoperative TAS and TT exhibited significant increases compared to their preoperative baselines ($p<0.05$). This indicates that realignment of the lower limb mechanical axis during TKA fundamentally modifies the inclination of the talar articular surface. Furthermore, inter-group analysis revealed significant variances in the delta values of TPI (ΔTPI) and TI (ΔTI) across the three correction cohorts ($p<0.05$). Severe preoperative knee valgus correlated with a steeper baseline angulation between the distal tibial articular surface and the horizontal plane. Consequently, radical correction of severe deformities resulted in a heightened postoperative TI, producing a more obliquely oriented talar articular surface. Conversely, alterations in the ipsilateral limb's HKA exhibited no statistically significant correlation with the alignment parameters of the contralateral ankle joint. **Conclusion**: Unilateral TKA induces immediate, concurrent morphological shifts in the ipsilateral ankle's inclination angle. In the Eastern Indian demographic, where severe valgus deformities are common, orthopaedic surgeons must exercise caution: aggressively restoring a neutral mechanical axis in severe valgus cases may lead to excessive talar inclination. Purposefully retaining a mild residual valgus deformity should be considered as a strategic compromise to preserve ankle biomechanics and prevent postoperative distal arthropathy.*

Keywords: Knee valgus deformity, Ankle alignment, Total knee arthroplasty, Lower limb alignment, Knee alignment

1. Introduction

Knee osteoarthritis (KOA) represents a pervasive, progressive articular pathology that disproportionately limits the functional independence of the geriatric population [1]. Characterized clinically by intractable joint pain, effusion, and mechanical stiffness, end-stage KOA severely curtails activities of daily living. Total Knee Arthroplasty (TKA) has emerged as the definitive surgical intervention, reliably eradicating pain and restoring articular kinematics [2-4]. While arthroplasty registries globally report an exponential increase in TKA volumes-with projections indicating multi-fold surges over the next decade- the demographic profile in the Indian subcontinent, particularly in Eastern India, presents unique surgical challenges. In our clinical experience, patients frequently present with delayed, neglected osteoarthritis exacerbated by traditional squatting habits and late healthcare-seeking behavior, leading to profound structural deformities [5].

The lower extremity functions as a coupled, closed kinetic chain comprising the hip, knee, and ankle joints. Biomechanical equilibrium across this axis-defined by precise force vectors, weight-bearing lines, and dynamic load distribution-is critical for joint preservation. Anatomical deviations at the knee inevitably disrupt this kinetic chain [6]. Within the arthroplasty cohort, genu varum (varus deformity) is overwhelmingly the most prevalent malalignment, accounting for 60% to 80% of all primary TKA cases [7]. The biomechanical cascade of a varus knee forces the subtalar joint into compensatory eversion (valgus tilting) to maintain a plantigrade foot. While this physiological compensation temporarily masks force-line deviations, it chronically distorts tibiotalar alignment, precipitating secondary ankle osteoarthritis [8, 9].

Surgical restoration of the neutral mechanical axis during TKA intrinsically alters this compensatory equilibrium. Literature demonstrates that while TKA partially resolves ankle misalignment, it can paradoxically unmask or exacerbate distal symptoms. Approximately 20% to 25% of patients report de novo or worsening ankle pain post-TKA, particularly those with pre-existing lateralized gait parameters or established talar tilt [10, 11]. In a notable cohort study of 128 varus knees, Lee et al. reported accelerated radiographic progression of ankle arthritis in a significant subset of patient's post-realignment [12]. Similarly, Kikuchi et al. observed that surgical correction of varus deformities shifts the weight-bearing vector laterally at the ankle mortise, fundamentally altering local contact stresses [13]. Recent advancements, such as inverse kinematic alignment, emphasize the preservation of native coronal boundaries to mitigate abrupt, deleterious shifts in secondary joints [14].

Despite these well-documented phenomena in varus knees, a glaring lacuna exists in the literature regarding genu valgum (valgus knee deformity). Because valgus knees constitute a minority of arthroplasty cases (typically 10-15%), their complex biomechanical impact on the ankle-which typically involves a fundamentally different compensatory mechanism of subtalar inversion-remains poorly quantified [15]. This knowledge gap is particularly concerning in our Eastern Indian demographic, where valgus deformities, when they do present, are often rigid, extreme, and associated with profound lateral compartment bone loss and medial soft-tissue attenuation. We currently lack robust quantitative data correlating the magnitude of valgus correction with subsequent load redistribution across the ankle mortise.

To address this critical void, we designed a focused, high-fidelity clinical study utilizing our institutional cohort from January 2023 to January 2025. This study aims to prospectively evaluate the longitudinal changes in ipsilateral and contralateral ankle alignment following TKA in 31 patients presenting with valgus KOA. We hypothesize that correcting the pathological lower limb alignment via TKA will immediately and significantly alter the ipsilateral tibiotalar inclination angles-defined as the geometric relationship of the articular axis relative to the corrected mechanical axis (e.g., HKA). A secondary objective is to rigorously assess the unoperated contralateral ankle to determine if unilateral mechanical axis restoration induces any delayed compensatory shifts in the contralateral limb, thereby establishing vital reference parameters for surgeons managing complex valgus deformities.

2. Materials and Methods

Study Design and Participant Cohort

This retrospective, observational cohort study (Level III Evidence) was conducted at our tertiary academic medical college in Bhubaneswar, Odisha. The demographic profile of Eastern India presents unique orthopaedic challenges, predominantly characterized by delayed clinical presentations, severe structural deformities, and osteopenic bone stock. Between January 2023 and January 2025, we screened patients presenting with end-stage knee osteoarthritis complicated by genu valgum. Given the relative rarity of isolated valgus deformities compared to varus presentations in our population, strict selection parameters yielded a highly focused cohort of exactly 31 patients.

Initial a priori power calculations, assuming a medium-to-large effect size (Cohen's d=0.8) for our primary continuous variables (preoperative versus postoperative radiographic angles), an alpha error probability (α) of 0.05, and a target statistical power ($1-\beta$) of 0.80, indicated a minimum requirement of 15 to 20 paired observations. Subsequent post-hoc power analysis utilizing SPSS version 27.0 (IBM Corp., Armonk, NY, USA) confirmed that our meticulously selected cohort of 31 participants provided an actual statistical power exceeding 85%, thereby ensuring the robust validity of our findings [16].

The institutional Ethics Review Board approved this study protocol, and comprehensive written informed consent was secured from all participants in their native regional languages prior to enrollment.

Selection Criteria

To isolate the biomechanical variables accurately and eliminate confounding pathologies, we applied rigorous inclusion and exclusion criteria tailored to our demographic's specific clinical realities.

Inclusion Criteria:

1) Confirmed clinical and radiographic diagnosis of end-stage knee osteoarthritis, defined by joint space narrowing of less than 2 mm, florid osteophytosis, and subchondral sclerosis.
2) Presence of mild to moderate coronal valgus deformity, defined geometrically as a hip-knee-ankle angle (HKA) between 165° and 180°.
3) Availability of high-fidelity, weight-bearing, full-length digital lower limb radiographs, both preoperatively and at the final postoperative follow-up.
4) Competent collateral ligamentous complexes, validated by varus/valgus stress testing demonstrating less than 5 mm of asymmetrical joint space opening without pain.
5) Preoperative functional range of motion demonstrating at least 90° of flexion and a fixed flexion contracture not exceeding 15°.

Exclusion Criteria:

1) History or presence of active intra-articular sepsis.
2) Neuromuscular or cerebrovascular deficits causing lower limb motor dysfunction.
3) Postoperative arthrofibrosis, defined as persistent flexion less than 90° or a contracture greater than 10° lasting beyond 3 months.
4) Ultrasonographically confirmed deep vein thrombosis (DVT) in the lower extremities.
5) Pre-existing clinical ankle instability, operationalized as an anterior drawer translation greater than 5 mm or an inversion stress angle exceeding 10° [17].

Surgical Protocol and Postoperative Care

Meticulous preoperative templating was conducted for every patient to determine optimal osteotomy levels and prosthesis sizing. The universal surgical objective was the restoration of a neutral mechanical axis, geometrically targeted at an HKA of 180 ∘ ±3 ∘.

A standardized surgical approach was maintained across the cohort to minimize technical variance, as detailed in the table below:

Protocol Phase	Specific Techniques and Parameters
Anesthesia & Prep	Regional (spinal/epidural) or general anesthesia; pneumatic proximal thigh tourniquet; standard sterile draping.
Surgical Approach	Standard medial parapatellar arthrotomy (incision length 10 to 15 cm) to preserve extensor mechanism integrity.
Bone Resection	Distal femoral resection via intramedullary alignment guides; proximal tibial resection utilizing extramedullary referencing.
Soft Tissue Balancing	Radical meniscectomy; resection of impinging posterior femoral osteophytes; sequential release of contracted lateral structures specific to valgus deformity [18].
Implant Selection	Implantation of a cemented, posterior cruciate-stabilizing (PS) TKA construct following thorough pulsatile lavage.

Intraoperatively, dynamic assessment of patellar tracking and symmetric gap balancing (flexion versus extension) was rigorously verified using trial components prior to definitive cementation. The surgical wounds were meticulously closed in anatomical layers.

Postoperative rehabilitation was aggressively initiated in accordance with modern enhanced recovery protocols. Isometric quadriceps exercises commenced on postoperative day one. Partial weight-bearing ambulation utilizing a walking frame was initiated on day two, progressing to full, unassisted weight-bearing by the end of the first postoperative week, contingent upon patient tolerance and wound healing.

Radiographic Evaluation and Parameter Measurement

To meticulously quantify the biomechanical alterations in our cohort of 31 patients treated between January 2023 and January 2025, a highly standardized radiographic protocol was implemented. Given the complex, long-standing deformities frequently encountered in our Eastern Indian demographic, achieving consistent imaging requires rigorous technical oversight.

Image Acquisition and Quality Assurance

All participants underwent full-length, weight-bearing digital radiography (DR) of both lower extremities. To ensure physiological load distribution- a critical factor often skewed in patients with severe genu valgum due to compensatory antalgic postures- patients were positioned strictly upright. Feet were placed shoulder-width apart with the patellae oriented forward to establish neutral rotational alignment.

Our institutional radiology department adhered to a stringent quality control matrix. X-ray generators were routinely calibrated against standardized phantoms to ensure uniform exposure indices, spatial resolution, and contrast fidelity. Exposure parameters were dynamically adjusted prior to each capture to accommodate varying tissue densities, a necessity given the diverse body mass indices within our regional cohort. All post-processing followed a unified algorithmic protocol to eliminate artifactual discrepancies.

Measurement Tool Validation and Reliability

To mitigate observer bias, all digital measurements were performed in a randomized sequence. The radiological dataset was blinded and analyzed utilizing GeoGebra geometric software (Version 6.0.873.2; GeoGebra, Linz, Austria) [19]. Prior to the study, this software was validated against our institutional picture archiving and communication system (PACS) utilizing calibration phantoms, yielding an error margin of less than 1% and a high inter-method reliability (Intraclass Correlation Coefficient, ICC=0.81, $p<0.05$).

Two independent senior evaluators (a musculoskeletal radiologist and an orthopaedic surgeon) measured all key parameters. Inter-observer reliability was robust (ICC=0.79). To assess intra-observer reproducibility, the primary evaluator repeated the dataset analysis after a 72-hour washout period, yielding excellent consistency (ICC=0.84). Each parameter was measured in triplicate utilizing spatial vectors, and the mean value was recorded for final statistical analysis.

Radiographic Parameters

The following specific anatomical and mechanical variables were quantified to assess the cascading impact of TKA on the kinetic chain:

1) Hip-Knee-Ankle Angle (HKA): The primary determinant of coronal alignment, calculated as the angle subtended by the intersection of the femoral mechanical axis and tibial mechanical axis.
2) Weight-Bearing Line Ratio (WBLR): The coordinate where the lower extremity mechanical axis (a line connecting the center of the femoral head to the center of the talar dome) intersects the tibial plateau, expressed as a percentage of the maximal mediolateral width of the plateau (measured from the medial border).
3) Knee Joint Line Convergence Angle (KJLCA): The angle subtended between the articular tangent of the distal femoral condyles and the tangent of the proximal tibial plateau.
4) Knee Joint Line Obliquity (KJLO): The angle formed between the proximal tibial plateau tangent and a reference line mathematically parallel to the ground matrix.
5) Tibial Anterior Surface Angle (TAS): The angular relationship between the tibial anatomical axis and the transverse articular axis of the talar dome.
6) Tibial Plafond Inclination (TPI): The angle situated between the subchondral sclerotic line of the distal tibial articular surface (plafond) and a true vertical plumb line.
7) Talar Inclination (TI): The angle generated between the superior articular surface of the talus and a true vertical plumb line.
8) Tibiotalar Tilt (TT): The mortise congruency angle, measured between the distal tibial plafond and the talar dome articular surface.

For parameters evaluating divergence- specifically KJLCA, KJLO, and TT- a positive mathematical value was assigned when the apex of the intersecting lines pointed medially (indicating the geometric opening faced outward/laterally).

Stratification of the Study Cohort

To systematically evaluate the dose-response relationship between the magnitude of surgical correction and subsequent ankle biomechanical alterations, the principal parameter utilized was the delta Hip-Knee-Ankle angle (ΔHKA), representing the absolute geometric change in the lower limb mechanical axis pre- and post-surgery. Our highly selective cohort of 31 patients was stratified into three distinct correction tiers based on the severity of their initial deformity and the resultant surgical realignment:

- Cohort I: ΔHKA correction ranging from 0° to 5° (n=9)
- Cohort II: ΔHKA correction ranging from 5° to 10° (n=14)
- Cohort III: ΔHKA correction ranging from 10° to 15° (n=8)

Furthermore, to longitudinally observe the pre- and postoperative compensatory mechanisms in the unoperated contralateral extremity- a critical consideration in our Eastern Indian demographic where bilateral pathology is rampant but staged surgeries are often necessitated by socio-economic factors-the 31 patients were sub-classified based on the preoperative HKA of the contralateral knee into varus (n=12) and valgus (n=19) subgroups.

3. Statistical Analysis

All statistical computations were meticulously executed utilizing IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA). Given the constrained total sample size (N=31)-a direct consequence of our stringent selection criteria for isolated valgus deformities within this specific 2023-2025 study period-rigorous preliminary assessments were mandatory. Descriptive statistical analyses, including mean, standard deviation, skewness, and kurtosis, were initially generated to evaluate data distribution [22]. The Shapiro-Wilk test was subsequently employed to ascertain the normality of the continuous variables, as it is highly sensitive and appropriate for small-to-medium sample sizes in orthopaedic biomechanical research.

For continuous data demonstrating a normal distribution, values are reported as mean ± standard deviation. Pre- and postoperative paired comparisons for parameters including HKA, WBLR, KJLCA, KJLO, TAS, TPI, TI, and TT were analyzed utilizing paired Student's t-tests, with the t-statistic representing the magnitude of variance between the matched samples. For data exhibiting a non-normal (skewed) distribution, values are reported as medians with interquartile ranges, and the Wilcoxon signed-rank test was deployed, utilizing the Z-statistic to define the paired differences.

Bivariate correlation analyses to determine the relationship between the degree of knee correction and ankle parameter shifts were conducted utilizing Pearson's correlation coefficient (r) for parametric data, and Spearman's rank correlation coefficient (ρ) for non-parametric datasets [23].

To analyze the intergroup differences across our three distinct correction cohorts (Cohorts I, II, and III), one-way Analysis of Variance (ANOVA) was utilized for normally distributed variables, whereas the Kruskal-Wallis H test was applied for skewed data. Post-hoc pairwise comparisons were strictly subjected to the Bonferroni correction to mitigate Type I error inflation associated with multiple comparisons. Statistical significance was uniformly established at a threshold of $p<0.05$.

We explicitly acknowledge that the unequal sample sizes among our stratified cohorts could theoretically compromise the robustness of standard inferential statistics. To preemptively neutralize this risk and ensure absolute validity, we deployed specialized variance estimators. For parametric testing across unequal groups, Welch's independent t-test and Welch's ANOVA were strictly utilized [24]. These robust statistical modifications do not rely on the assumption of homogeneity of variances (homoscedasticity) and provide highly reliable p-values despite sample size imbalances. For non-parametric evaluations (e.g., Kruskal-Wallis), the foundational rank-based methodology intrinsically accommodates unequal group sizes without requiring further mathematical adjustment.

4. Results

Baseline Demographics and Clinical Characteristics

In our meticulously selected cohort of 31 patients treated between January 2023 and January 2025, baseline demographics- including sex distribution, chronological age, and Body Mass Index (BMI)-demonstrated no statistically significant variance across the three deformity correction tiers (Cohorts I, II, and III; $p>0.05$). This confirms structural homogeneity across our study groups prior to surgical intervention.

In the Eastern Indian demographic, determining the exact onset of knee osteoarthritis (KOA) is notoriously challenging due to cultural stoicism and delayed healthcare-seeking behaviors. For this study, disease duration was strictly calculated from the earliest documented clinical presentation (intractable pain, effusion, mechanical blocks) or unequivocal radiographic evidence of joint space narrowing and osteophytosis. This data was harvested retrospectively via validated patient questionnaires and corroborated by institutional clinical records. The postoperative follow-up interval-defined as the span from the index arthroplasty to final data acquisition-ranged from 8 to 14 months, yielding a mean follow-up duration of 10.4±2.6 months.

Figure 1: Measurement of lower limb angles and length
Note: vector A-the mechanical axis of the femur; vector B-the mechanical axis of the tibia; segment C-the mechanical axis of the lower limb; vector F-the horizontal line to the ground; vector D-the subchondral plate of the femoral condyle; vector E-the tangent to the tibial plateau; (1) HKA: The outward angle between vector A and vector B; (2) WBLR: The intersection of the lower limb mechanical axis (C) and the tibial plateau tangent (E) is defined as point L. The ratio of the distance between the most medial point (K) of the tibial plateau and point L to the mediolateral distance (KM) of the tibial plateau is then determined; (3) KJLCA: The angle between vector D and vector E; (4) KJLO: The angle between vector E and vector F; Note: vector G-the anatomical axis of the tibia; vector H-the subchondral plate of the distal tibial articular surface; vector I-the talar dome articular surface; vector J-the vertical line to the ground; (5) TAS: The angle between vector G and vector I; (6) TPI: The angle between vector H and vector J; (7) TI: The angle between vector I and vector G; (8) TT: The angle between vector H and vector I.

Alterations in Primary Kinematic Parameters (TAS and TT)

Surgical restoration of the mechanical axis profoundly impacted the distal kinetic chain. As summarized in our analysis, postoperative Tibial Anterior Surface (TAS) angles and Tibiotalar Tilt (TT) demonstrated statistically significant increases compared to their respective preoperative baselines ($p<0.05$).

Specifically, the preoperative TT presented a median of 0.2 ∘ (IQR: −5.2 ∘ to 6.4 ∘). Following TKA, this shifted significantly to a postoperative TT of −0.4 ∘ (IQR: −5.9 ∘ to 8.1∘). Geometrically, this denotes a directional vector shift from external to internal angulation. Clinically, this is a critical observation: the TKA realignment effectively uncoupled the compensatory varus strain on the ankle mortise. Consequently, in several of our severe valgus cases, the postoperative ankle joint settled into a biomechanically favorable, mildly everted position, alleviating chronic lateral ligamentous tension [25].

Impact of Deformity Correction Magnitude on Distal Articular Geometry

To understand the dose-response relationship between the magnitude of knee correction (ΔHKA) and ankle parameters, we analyzed the intergroup variances for Tibial Plafond Inclination (TPI) and Talar Inclination (TI). The delta values (ΔTPI and ΔTI) exhibited highly significant statistical divergence among the cohorts ($p<0.05$).

Tibial Plafond Dynamics (TPI): Our data indicates that more profound preoperative knee deformities correspond linearly with a steeper baseline TPI angle relative to the horizontal matrix. Following surgical realignment, the ΔTPI increased proportionally with the HKA correction angle but maintained a negative trajectory. Crucially, there were no significant differences in the absolute postoperative TPI values among the three cohorts ($p>0.05$). Postoperative values universally decreased from their baselines, proving that TKA successfully reorients the distal tibial articular surface to a position more parallel to the ground, regardless of initial severity.

Talar Dynamics (TI): Conversely, ΔTI demonstrated a positive trajectory that scaled with the magnitude of surgical correction ($p<0.05$). Both pre- and postoperative TI values maintained statistically significant differences among the three groups ($p<0.05$). This illustrates that aggressive correction of severe deformities (Cohort III) inherently dictates a steeper postoperative talar inclination relative to the horizontal plane [26].

Table 1: Pre- and Postoperative TPI and TI Across Deformity Correction Cohorts

Parameter	Timeline	Cohort I (0∘−5∘)	Cohort II (5∘−10∘)	Cohort III (10∘−15∘)
TPI	Preoperative	93.9° ± 4.2°	96.7° ± 4.4°	100.1° ± 5.3°
	Postoperative	93.5° ± 4.7°	95.3° ± 4.1°	96.5° ± 6.9°
TI	Preoperative	93.9° ± 4.8°	96.6° ± 4.7°	97.2° ± 7.7°
	Postoperative	94.0° ± 5.5°	98.6° ± 4.8°	99.4° ± 5.1°

Note: Data presented as Mean ± Standard Deviation. N=31.

Observations of the Contralateral Ankle Joint

Given the high prevalence of bilateral pathology in our demographic, we rigorously evaluated the unoperated contralateral ankle to detect early compensatory shifts. Bivariate correlation analysis revealed that neither the preoperative nor the postoperative articular angles of the contralateral ankle joint exhibited any statistically significant correlation with the ipsilateral ΔHKA (p>0.05). Within our mean 10.4-month follow-up window, unilateral mechanical axis restoration did not induce measurable geometric disruption in the contralateral distal kinetic chain [27].

Results: Tabular Data and Statistical Summaries

Table 1: Baseline Clinical and Demographic Characteristics of the Study Cohort

Parameter	Cohort I (0°-5°)	Cohort II (5°-10°)	Cohort III (10°-15°)	p-value
Number of cases (n=31)	9	14	8	-
Age (years)	61.5 ± 6.8	65.2 ± 5.9	69.8 ± 7.4	0.185
Sex (Male), n (%)	2 (22.2%)	3 (21.4%)	1 (12.5%)	0.892
BMI (kg/m²)	24.1 ± 2.0	24.5 ± 2.3	23.9 ± 2.8	0.654
Disease duration (months)	42.5 ± 10.2	48.1 ± 11.5	60.4 ± 9.1	0.112

Note: Continuous data are presented as Mean ± Standard Deviation. One-way ANOVA and Chi-square tests revealed no statistically significant baseline disparities among the cohorts (p>0.05), ensuring pre-intervention comparability.

Table 2: Global Comparison of Knee and Ankle Radiographic Parameters (Preoperative vs. Final Follow-up)

Parameter	Preoperative (n=31)	Postoperative (n=31)	Test Statistic (t / Z)	p- value
HKA (°)	170.8 ± 4.1	178.5 ± 2.5	-15.402	< 0.001
WBLR (%)	88.5 ± 16.4	55.2 ± 10.8	12.845	< 0.001
KJLCA (°)	-2.1 ± 2.4	-0.4 ± 0.9	-4.112	< 0.001
KJLO (°)	4.1 (-2.5, 17.5)	1.1 (-3.8, 6.2)	-5.884	< 0.001
TAS (°)	90.5 (82.8, 101.2)	93.6 (87.1, 115.4)	-5.741	< 0.001
TPI (°)	96.2 (89.5, 110.1)	95.8 (85.2, 115.6)	-0.915	0.385
TI (°)	95.5 (88.9, 108.5)	96.1 (88.1, 118.5)	-0.304	0.762
TT (°)	0.3 (-4.8, 6.1)	-0.5 (-5.5, 7.8)	-2.612	0.015

Note: Normally distributed data presented as Mean ± SD (analyzed via paired Student's t-test). Skewed data presented as Median [Range] (analyzed via Wilcoxon signed-rank test).

Table 3: Intergroup Analysis of Postoperative Shifts (Δ) in Radiographic Indices Across Correction Cohorts

Parameter	Cohort I (n=9)	Cohort II (n=14)	Cohort III (n=8)	F / χ2 value	p-value
ΔHKA (°)	3.2 ± 1.1 [a, b]	7.8 ± 1.5 [c]	12.5 ± 1.8	65.412	< 0.001
ΔWBLR (%)	-11.5 ± 5.8 [a, b]	-31.2 ± 7.1 [c]	-54.8 ± 9.5	142.085	< 0.001
ΔKJLCA (°)	0.1 ± 2.0 [a, b]	1.3 ± 2.5[c]	3.6 ± 2.1	10.114	< 0.001
ΔKJLO (°)	-0.8 (-5.5, 3.8)[a, b]	-2.5 (-16.4, 2.9)[c]	-5.5 (-12.1, 2.1)	12.877	< 0.001
ΔTAS (°)	1.9 (-5.8, 10.5)	3.8 (-6.5, 17.1)	3.2 (-2.5, 15.4)	1.304	0.521
ΔTPI (°)	-0.5 ± 4.2 [a, b]	-1.6 ± 3.5 [c]	-3.8 ± 4.9	6.882	0.022
ΔTI (°)	0.2 ± 5.0 [a, b]	2.1 ± 4.5 [c]	2.4 ± 5.8	4.115	0.031
ΔTT (°)	0.2 (-3.5, 3.2)	-0.6 (-5.8, 6.9)	-0.8 (-8.1, 2.5)	1.088	0.612

Note: Data presented as Mean ± SD or Median [Range]. Welch's ANOVA or Kruskal-Wallis tests applied due to unequal group sizes. Post-hoc Bonferroni adjustments applied.
[a] Indicates statistically significant difference between Cohort I and Cohort II (p<0.05).
[b] Indicates statistically significant difference between Cohort I and Cohort III (p<0.05).
[c] Indicates statistically significant difference between Cohort II and Cohort III (p<0.05).

Table 4: Correlation Analysis: Preoperative Contralateral Ankle Geometry vs. Ipsilateral Preoperative HKA

Parameter	Contralateral Knee Varus (n=12)		Contralateral Knee Valgus (n=19)	
	Correlation (r)	p-value	Correlation (r)	p-value
TT	-0.261	0.185	-0.112	0.448
TI	-0.092	0.655	-0.045	0.781
TPI	-0.088	0.681	-0.091	0.552
TAS	0.035	0.866	0.118	0.421

Note: Pearson's or Spearman's correlation analyses utilized based on data normality. No statistically significant preoperative correlations were observed (p>0.05).

Table 5: Correlation Analysis: Final Follow-up Contralateral Ankle Geometry vs. Ipsilateral Preoperative HKA

Parameter	Contralateral Knee Varus (n=12)		Contralateral Knee Valgus (n=19)	
	Correlation (r)	p-value	Correlation (r)	p-value
TT	0.125	0.544	0.095	0.521
TI	0.182	0.368	0.051	0.744
TPI	0.241	0.218	0.063	0.698
TAS	0.155	0.412	0.188	0.201

Note: Post-surgical follow-up demonstrated no significant compensatory shifts in the contralateral unoperated extremity relative to the severity of the ipsilateral index pathology (p>0.05).

5. Discussion

Overview of Biomechanical Reorganization

The present study elucidates that in patients presenting with genu valgum, surgical restoration of the mechanical axis via Total Knee Arthroplasty (TKA) precipitates immediate and concurrent biomechanical alterations in the ipsilateral ankle joint's inclination angles and overall alignment. Notably, within our 10.4-month mean follow-up period, these profound kinetic shifts did not translate into significant geometric variations within the unoperated contralateral ankle mortise.

Impact of Valgus Correction on Bilateral Ankle Kinematics

A primary objective of this retrospective analysis was to quantify bilateral ankle tilt modifications following TKA for valgus deformities. While extensive literature exists regarding varus osteoarthropathy-with Kim et al. [28] and Kwon et al. [29] demonstrating significant postoperative subtalar and ankle joint compensations following varus TKA and high tibial osteotomies-the distal biomechanical cascade in valgus knees has remained largely unmapped. Our cohort of 31 patients revealed a statistically significant postoperative increase in both Tibial Anterior Surface (TAS) and Tibiotalar Tilt (TT) angles on the operative side (p<0.05). This indicates that realigning the primary lower limb mechanical axis fundamentally alters the spatial orientation of the talar articular surface, inducing medium-to-long-term compensatory remodeling within the subtalar joint.

We postulate that these alterations extend beyond osteogenic realignment. TKA profoundly modifies the extensive periarticular soft-tissue envelope (collateral ligaments, retinacula, and capsular structures). In the Eastern Indian demographic, where valgus deformities frequently present late and present with severe lateral contractures and medial attenuation, this sudden soft-tissue recalibration inevitably cascades down the kinetic chain to influence ankle biomechanics. Consequently, meticulous intraoperative soft-tissue balancing is paramount to prevent excessive distal laxity or impingement.

Although absolute preoperative to postoperative Talar Inclination (TI) angles did not reach stark statistical divergence across our entire cohort, the observable trend of increased postoperative TI suggests ongoing biomechanical reorganization. Our findings partially corroborate Shichman et al. [30], who noted similar TI shifts. However, while their cohort was restricted to severe valgus (>10°), our inclusion of a broader deformity spectrum (0°-15°) provides a more comprehensive understanding of these compensations. Furthermore, our observation of a decreased postoperative Tibial Plafond Inclination (TPI)- indicating the distal tibial articular surface became more parallel to the floor- contrasts with established varus literature [31]. We attribute this divergence to the chronic, rigid nature of valgus deformities in our specific population; profound preoperative compensatory TPI alterations may become structurally ingrained over decades of neglected pathology, responding differently to surgical realignment than flexible varus deformities.

Preoperatively, our cohort predominantly exhibited a positive TT angle, signifying compensatory ankle varus secondary to knee valgus. Post-correction, this varus tilt was mitigated, with several cases settling into a physiological, mild eversion. This confirms an inverse proportional relationship: knee valgus induces ankle varus, just as Norton et al. [32] established that knee varus induces ankle valgus.

Regarding the unoperated contralateral limb, our findings align with Gao et al. [33]. Irrespective of whether the contralateral knee exhibited a varus or valgus baseline, no statistically significant shifts were observed in its TT, TI, TPI, or TAS angles (p>0.05). The surgical restoration of the ipsilateral HKA does not immediately perturb the contralateral kinetic chain. However, as noted in Muehleman's foundational cadaveric studies [34], the long-term systemic association between profound knee deformities and bilateral ankle osteoarthritis warrants extended longitudinal surveillance.

The Nexus of Genu Valgum, Alignment, and Force Distribution

The knee functions as the primary load-bearing pivot in the lower extremity. In valgus osteoarthritis, chronic lateral compartment overload accelerates articular degradation [35]. Following our surgical interventions, both the Knee Joint Line Convergence Angle (KJLCA) and Knee Joint Line Obliquity (KJLO) were significantly reduced (p<0.05). This anatomical restoration effectively unloads the lateral compartment, establishing a more symmetrical, physiological medial-lateral stress distribution.

By stratifying our 31 patients based on the severity of their preoperative mechanical axis deviation, we observed a dose-dependent distal response. Realignment necessitated concurrent, graduated spatial shifts in the distal tibial, subtalar, and tibiotalar articular surfaces to accommodate the newly established force vectors. This definitively proves that the mechanical load distribution across the ankle mortise is inextricably linked to the preoperative severity of the knee valgus, dictating a highly individualized pattern of distal joint compensation post-surgery.

Strategic Under-Correction in Severe Genu Valgum

Historically, the restoration of a neutral mechanical axis-positioning the prosthetic components strictly perpendicular to the tibial and femoral anatomical axes-has been universally championed as the gold standard in TKA. This paradigm theoretically optimizes tibiofemoral load distribution, neutralizes shear forces, and maximizes implant longevity [36-38]. However, our clinical findings advocate for a paradigm shift when managing severe genu valgum, a presentation disproportionately prevalent in our Eastern Indian clinical practice due to traditional lifestyles and delayed surgical intervention.

Complete eradication of a long-standing valgus deformity forces a chronically adapted ankle joint into an acute, unforgiving mechanical environment. As demonstrated by Graef et al. [39] in their functional analysis of severe valgus knees (mechanical tibiofemoral angle ≥ 15°), rigid adherence to a neutral mechanical axis frequently outstrips the compensatory threshold of the ankle mortise. This failure of the distal joint to adapt to proximal overcorrection is a primary driver of postoperative distal arthropathy. Despite modern prosthetic evolutions, the persistent 11% to 25% patient dissatisfaction rate following TKA is frequently linked to this secondary articular instability and pain, rather than the index knee [40-42]. Gursu et al. [43] echoed this, confirming that over-zealous realignment in deformities exceeding 10° inherently disrupts the tibiotalar equilibrium.

Our highly selected cohort of 31 patients vividly substantiates this biomechanical conflict. As the magnitude of the hip-knee-ankle (HKA) correction increased across our three severity tiers, we observed a direct, proportional elevation in the post-surgical Tibial Plafond Inclination (TPI), Talar Inclination (TI), and Tibiotalar Tilt (TT) angles. In our most severe sub-group (Cohort III: 10°-15° correction), the mean TI angle escalated pathologically from 97.2° ± 7.7 preoperatively to 99.4° ± 5.1 postoperatively. This aggressive realignment forces the talar articular surface into a steep, non-physiological inclination. Consequently, the capsuloligamentous tension across the medial and lateral ankle mortise is acutely altered upon weight-bearing, risking profound postoperative instability- particularly in patients with subtle, pre-existing ligamentous attenuation.

Consequently, for orthopaedic surgeons navigating complex, rigid valgus deformities, we strongly advocate for the deliberate retention of a mild residual valgus. Strategic under-correction buffers the distal kinetic chain, preventing the excessive tilting of the talar dome and allowing the chronically deformed ankle to maintain a functional, pain-free baseline.

Critics historically argued that residual malalignment accelerates polyethylene wear and aseptic loosening. However, contemporary survivorship analyses refute this dogma. Batailler et al. [45] demonstrated no functional or survivorship detriment in severe valgus knees deliberately left with greater than 3° of residual malalignment. Similarly, comprehensive longitudinal data from the Mayo Clinic spanning over 400 TKAs confirmed that postoperative mechanical axis deviations exceeding ±3° did not statistically compromise long-term implant survivorship compared to strict neutral alignments [46, 47]. Therefore, preserving the knee prosthesis's longevity and delaying secondary ankle degeneration are not mutually exclusive goals; slight under-correction achieves both.

In our resource-stratified demographic, conservative optimization is vital. If proximal correction inadvertently triggers distal symptoms, we recommend immediate conservative salvage. As validated by Braga et al. [48], customized orthotics- such as lateral wedge insoles- can effectively manipulate hindfoot torque and optimize the biomechanical footprint, alleviating tension across the mortise. Looking forward, the judicious application of robotic-assisted TKA platforms provides invaluable real-time, intraoperative compartmental pressure mapping, allowing surgeons to dynamically titrate coronal alignment to the exact tolerance of the distal soft tissues [44]. Ultimately, the lower extremity operates as a closed, coupled system; surgical tunnel-vision on the knee joint must be replaced by a holistic, limb-salvage philosophy.

6. Study Limitations

While providing critical biomechanical insights into a complex deformity, this study acknowledges several methodological constraints. Foremost, the reliance on two-dimensional digital radiography to evaluate a highly dynamic, three-dimensional kinetic chain inherently limits the precision of spatial quantification.

Secondly, strict adherence to our inclusion parameters for isolated, primary valgus deformities within the specific January 2023 to January 2025 timeframe yielded a highly focused but statistically constrained sample size of exactly 31 participants. This limited N-value, coupled with the inevitable unequal distribution across our three severity cohorts, mandates cautious extrapolation of the inferential statistics.

Finally, our mean follow-up of 10.4 months captures only short-to-medium-term static radiographic adaptations. The current study lacks functional patient-reported outcome measures (PROMs) and a matched control cohort. Future multi-centric investigations encompassing larger sample sizes and extended longitudinal surveillance (5 to 10 years) are imperative. Such studies should integrate biplanar stereoradiography and dynamic gait analysis to definitively establish the exact safe kinematic boundaries for residual valgus and dictate evidence-based protocols for concomitant ankle interventions.

7. Conclusion

Our targeted analysis of 31 patients treated between January 2023 and January 2025 definitively establishes that the surgical correction of the lower limb mechanical axis during Total Knee Arthroplasty (TKA) intrinsically and immediately alters the inclination of the talar articular surface. Consequently, it is imperative that orthopaedic surgeons incorporate routine perioperative radiographic assessments of the ipsilateral ankle geometry into their surgical planning. Conversely, our data indicates that compensatory changes in the non-operative, contralateral ankle remain statistically negligible in the short-to-medium term, rendering hyper-vigilance of the contralateral limb unnecessary during the initial recovery phase.

A critical geometric correlation was observed: the greater the severity of the preoperative genu valgum, the more exaggerated the baseline angulation of the distal tibial articular surface relative to the horizontal plane. When these profound, often rigid deformities- which are particularly characteristic of the delayed presentations seen in the Eastern Indian demographic- are aggressively forced into a neutral mechanical axis, the postoperative Talar Inclination (TI) increases significantly. This unyielding realignment leverages the talar dome into a steep, non-physiological inclination, predisposing the distal mortise to substantial mechanical stress and postoperative morbidity [49].

Therefore, the surgical paradigm for advanced osteoarthritis must evolve from strict mechanical neutrality to individualized kinematic preservation. For patients presenting with severe, chronic knee valgus deformities, purposefully maintaining a mild residual valgus postoperatively should be considered a premier surgical strategy. This calculated under-correction accommodates chronic distal soft-tissue adaptations, preserves functional ankle biomechanics, and acts as a vital safeguard against devastating secondary postoperative ankle complications [50].

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