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Original Research Article

Assessment of Mechanical Axis, Anatomical Axis and Q angle in Preoperative and Postoperative Total Knee Replacement Patients

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Conflict of interest: Nil

Abstract

Background: Despite successful implant positioning, functional outcomes following total knee arthroplasty (TKA) remain variable, suggesting that factors beyond conventional mechanical alignment may influence postoperative recovery. The role of multidimensional alignment correction, including anatomical axis and extensor mechanism alignment such as the quadriceps (Q) angle, remains incompletely understood. This study evaluated changes in lower limb alignment parameters following TKA and their association with functional outcomes.

Methods: In this prospective observational study, 95 consecutive patients undergoing primary TKA for advanced knee osteoarthritis were evaluated. Mechanical axis, anatomical axis, and Q angle were measured using standardized standing long-leg radiographs preoperatively and at six months postoperatively. Functional outcomes were assessed using Knee Society Score (KSS) and Oxford Knee Score (OKS) at baseline, three months, and six months. Correlation and multivariable linear regression analyses were performed to identify independent predictors of postoperative functional improvement.

Results: Significant postoperative correction was observed in mechanical axis (10.2° ± 3.9° to 1.7° ± 0.9°), anatomical axis (14.6° ± 3.7° to 6.3° ± 1.3°), and Q angle (20.1° ± 3.7° to 16.7°). Functional outcomes improved substantially, with combined KSS increasing from 76.1 to 164.8 and OKS from 18.6 to 40.5 at six months. Multivariable regression analysis identified Q angle correction as an independent predictor of improved postoperative functional outcomes.

Conclusion: Multidimensional alignment restoration following TKA, including optimization of extensor mechanism biomechanics, is significantly associated with improved early functional recovery, highlighting the importance of comprehensive alignment assessment during surgical planning.

Keywords: Total Knee Arthroplasty; Lower Limb Alignment; Mechanical Axis; Anatomical Axis; Q Angle; Patellofemoral Biomechanics; Functional Outcome.

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Introduction

Osteoarthritis of the knee is one of the most prevalent causes of chronic pain and disability worldwide and represents a major contributor to reduced mobility and impaired quality of life among the elderly population. The global burden of knee osteoarthritis continues to rise due to increasing life expectancy and obesity prevalence, resulting in a substantial increase in the utilization of total knee arthroplasty (TKA) as the definitive treatment for end-stage disease [1]. Although TKA reliably provides pain relief and functional improvement, approximately 15–20% of patients remain dissatisfied following surgery despite technically successful implantation, suggesting that factors beyond prosthesis survival

influence postoperative outcomes [2]. Restoration of appropriate lower limb alignment has traditionally been considered a fundamental objective of TKA. Conventional mechanical alignment techniques aim to achieve a neutral hip–knee–ankle axis to ensure balanced load transmission and minimize implant wear. Early landmark studies demonstrated increased implant failure and revision rates in knees with postoperative malalignment, thereby establishing neutral mechanical alignment within ±3° as the standard surgical target [3,4]. However, emerging clinical evidence indicates that mechanical axis restoration alone does not fully explain variability in postoperative functional recovery or patient satisfaction.

Increasing attention has therefore been directed toward the multidimensional nature of knee biomechanics following arthroplasty. While most previous investigations have focused predominantly on mechanical axis correction, comparatively limited emphasis has been placed on anatomical axis restoration and extensor mechanism alignment parameters such as the quadriceps (Q) angle. Coronal deformities alter quadriceps force vectors and patellofemoral tracking mechanics, potentially contributing to anterior knee pain, instability, and functional limitation after TKA[5]. Failure to address patellofemoral biomechanics may partly explain persistent symptoms observed in otherwise well-aligned prosthetic knees.

Contemporary alignment philosophies, including kinematic and patient-specific alignment strategies, have further challenged the universal applicability of neutral mechanical alignment. Proponents of kinematic alignment suggest preservation of constitutional limb alignment may improve functional outcomes and patient satisfaction [6]. Nevertheless, large registry analyses and systematic reviews continue to report higher revision risk associated with substantial coronal malalignment, indicating that restoration of biomechanical balance remains essential for long-term success [7]. These contrasting findings highlight an ongoing controversy regarding optimal alignment strategy and emphasize the need for comprehensive evaluation of multiple alignment parameters rather than isolated radiographic measurements.

Importantly, few clinical studies have simultaneously evaluated mechanical axis, anatomical axis, and Q angle correction while correlating these parameters with both surgeon-assessed and patient-reported functional outcomes using multivariable analytical models. A multidimensional assessment integrating tibiofemoral and patellofemoral biomechanics may provide improved understanding of mechanisms underlying postoperative recovery and patient satisfaction following TKA.

Therefore, the present study was designed to evaluate changes in mechanical axis, anatomical axis, and Q angle following total knee arthroplasty and to determine the association between alignment correction and postoperative clinical and functional outcomes. We hypothesized that comprehensive alignment restoration, including optimization of extensor mechanism biomechanics, would be independently associated with improved early functional recovery following TKA.

Materials and Methods

Study Design and Setting: This prospective observational study was conducted in the Department of Orthopaedics at a tertiary care teaching hospital between January 2022 and June 2024. The study aimed to evaluate changes in lower limb alignment parameters following total knee arthroplasty (TKA) and to determine the association between alignment correction and postoperative clinical and functional outcomes. Consecutive eligible patients undergoing primary TKA during the study period were recruited to minimize selection bias. Institutional Ethics Committee approval was obtained prior to study initiation. The study adhered to the principles of the Declaration of Helsinki, and written informed consent was obtained from all participants.

Sample Size Estimation: Sample size adequacy was determined based on expected postoperative improvement in Knee Society Score following TKA reported in previous literature. Assuming a moderate effect size (Cohen's d = 0.5), alpha error of 0.05, and statistical power of 80%, the minimum required sample size was calculated as 84 patients. Considering potential loss to follow-up, 95 patients were included in the final analysis.

Study Population: Patients diagnosed with advanced primary osteoarthritis of the knee scheduled for primary unilateral total knee arthroplasty were included.

Inclusion Criteria: Patients aged ≥50 years with symptomatic primary osteoarthritis refractory to conservative treatment and radiographic severity corresponding to Kellgren–Lawrence grade III or IV were eligible.

Exclusion Criteria: Patients with inflammatory arthritis, post-traumatic arthritis, prior knee surgery, severe extra-articular deformity, neuromuscular disorders affecting gait, revision arthroplasty, or incomplete follow-up were excluded. In patients with

bilateral disease, only the first operated knee was included for analysis to avoid statistical dependence.

Surgical Technique: All procedures were performed by experienced arthroplasty surgeons using a standardized medial parapatellar approach under regional anesthesia. Cemented posterior-stabilized prostheses from a single implant system were used in all cases to ensure procedural uniformity. Mechanical alignment principles were followed with the goal of restoring limb alignment within ±3° of neutral mechanical axis. Femoral bone cuts were performed using intramedullary alignment guides, while tibial resections utilized extramedullary guides. Soft tissue balancing was performed to achieve symmetrical flexion and extension gaps. Patellar resurfacing was performed selectively based on cartilage status, patellar tracking, and intraoperative surgeon assessment. Postoperative rehabilitation protocols were standardized and included early mobilization, quadriceps strengthening exercises, range-of-motion training, and progressive weight-bearing beginning on postoperative day one.

Radiological Assessment: Radiological evaluation was performed preoperatively and at six months postoperatively using standardized standing full-length hip–knee–ankle radiographs. Radiographs were obtained with patients in full knee extension, patella facing forward, and equal weight-bearing to minimize rotational error. Digital calibration tools were used for measurement consistency. The following parameters were assessed:

- Mechanical Axis (MA): Angle between the hip–knee–ankle mechanical line.
- Anatomical Axis (AA): Angle formed by femoral and tibial anatomical axes.
- Q Angle: Angle between quadriceps line of pull and patellar tendon axis.

Measurements were independently performed by two blinded orthopedic observers. Interobserver and intraobserver reliability were assessed using intraclass correlation coefficients (ICC), demonstrating excellent agreement (ICC >0.85).

Clinical and Functional Outcome Assessment: Clinical and functional outcomes were evaluated using validated scoring systems:

- Knee Society Score (KSS) including knee and functional components.
- Oxford Knee Score (OKS) as a patient-reported outcome measure.

Outcome assessment was conducted preoperatively and at 3-month and 6-month follow-up visits by independent evaluators blinded to radiological measurements to reduce observer bias.

Follow-Up and Data Completeness: Patients were followed prospectively at standardized intervals. Follow-up completion rate at six months was 100%, and no patients were lost to follow-up. Compliance with rehabilitation protocols was monitored during outpatient visits.

Data Variables: Demographic data including age, gender, body mass index (BMI), and operated side were recorded. Alignment correction variables were calculated as the difference between preoperative and postoperative measurements. Functional improvement was defined as change in KSS and OKS between baseline and six months postoperatively

Statistical Analysis: Statistical analysis was performed using SPSS software version 26.0 (IBM Corp., Armonk, NY, USA).Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Normality of data distribution was assessed using the Shapiro–Wilk test. Preoperative and postoperative comparisons were analyzed using paired t-tests. Longitudinal functional outcome changes were evaluated using repeated-measures analysis. Pearson correlation analysis was performed to assess relationships between alignment correction and functional improvement.

Multivariable linear regression models were constructed to identify independent predictors of six-month functional outcomes. Multicollinearity was assessed using variance inflation factor (VIF), and regression assumptions including linearity, homoscedasticity, and residual normality were verified prior to analysis. Regression coefficients (β), standard errors, 95% confidence intervals, and p-values were reported. Statistical significance was defined as $p < 0.05$.

Result

Baseline demographic, clinical, and preoperative alignment characteristics of patients undergoing total knee arthroplasty were summarized in Table 1. The study population had a mean age of 66.2 years with a female predominance. Most patients presented with varus knee deformity prior to surgery.

Preoperative radiological assessment demonstrated substantial deviation of both mechanical and anatomical axes along with increased Q angle, indicating significant coronal malalignment and altered extensor mechanism biomechanics. Functional evaluation showed low baseline Knee Society Scores and Oxford Knee Scores, reflecting marked pain and functional limitation before surgical intervention. Overall, the table confirms a

comparable and clinically appropriate cohort of advanced osteoarthritis patients requiring total knee replacement.

Table 1: Baseline Demographic, Clinical and Preoperative Alignment Characteristics (n = 95)

Variable	Value
Age (years)	66.2 ± 8.4
Gender	
Male	38 (40.0%)
Female	57 (60.0%)
Body Mass Index (kg/m²)	28.1 ± 3.6
Operated Side	
Right Knee	49 (51.6%)
Left Knee	46 (48.4%)
Preoperative Mechanical Axis (°)	10.16 ± 3.93
Preoperative Anatomical Axis (°)	14.64 ± 3.74
Preoperative Q Angle (°)	20.12 ± 3.70
Preoperative KSS – Knee Score	39.8 ± 11.6
Preoperative KSS – Functional Score	36.3 ± 13.2
Combined Knee Society Score	76.12 ± 22.4
Preoperative Oxford Knee Score	18.56 ± 6.1
Predominant Deformity	
Varus Alignment	78 (82.1%)
Valgus Alignment	17 (17.9%)

BMI, Body Mass Index; MA, Mechanical Axis; AA, Anatomical Axis; KSS, Knee Society Score; OKS, Oxford Knee Score; SD, Standard Deviation.

Table 2 presents the radiological alignment outcomes following total knee arthroplasty, demonstrating significant correction of lower limb alignment parameters. Both mechanical and anatomical axes showed substantial improvement toward physiological alignment postoperatively, indicating effective restoration of coronal plane balance. Additionally, a reduction in Q angle was observed, reflecting improved extensor mechanism alignment and patellofemoral biomechanics. Overall, the findings confirm that total knee arthroplasty achieved consistent and clinically meaningful correction of limb alignment across the study population.

Table 2: Radiological Alignment Correction Following Total Knee Arthroplasty

Parameter	Preoperative (Mean ± SD)	Postoperative (Mean ± SD)	Mean Correction	% Improvement
Mechanical Axis (°)	10.16 ± 3.93	1.73 ± 0.87	8.43	83.0%
Anatomical Axis (°)	14.64 ± 3.74	6.28 ± 1.31	8.36	57.1%
Q Angle (°)	20.12 ± 3.70	16.71 ± 7.56	3.41	16.9%

MA, Mechanical Axis; AA, Anatomical Axis; Q angle, Quadriceps Angle; SD, Standard Deviation; TKA, Total Knee Arthroplasty.

Figure 1 illustrates the significant improvement in mechanical axis alignment following total knee arthroplasty. A marked reduction in mean mechanical axis deviation is observed postoperatively compared with the preoperative state, demonstrating effective restoration of neutral lower limb alignment.

Error bars represent standard deviation, indicating reduced variability and consistent surgical correction across the study population.

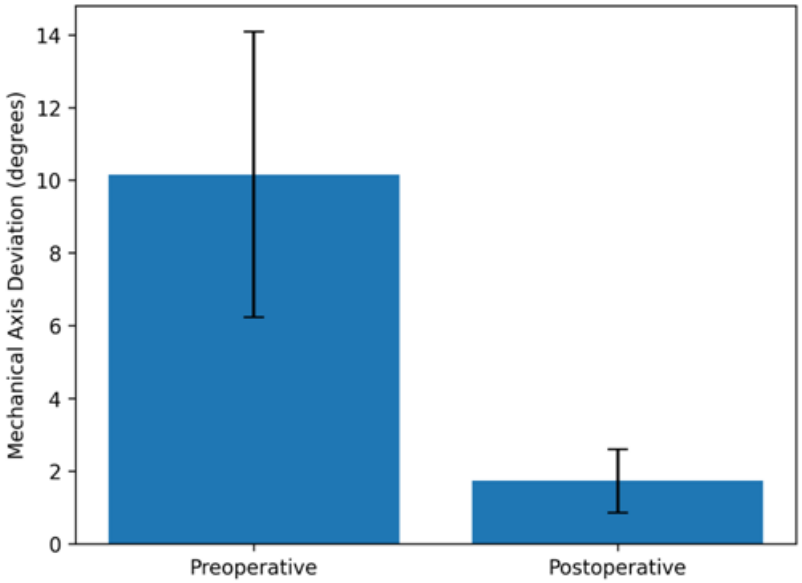

Figure 1: Mechanical axis alignment before and after total knee arthroplasty

Figure 2 demonstrates the reduction in mean Q angle following total knee arthroplasty, indicating improvement in extensor mechanism alignment and patellofemoral biomechanics after correction of coronal limb deformity.

Error bars represent standard deviation.

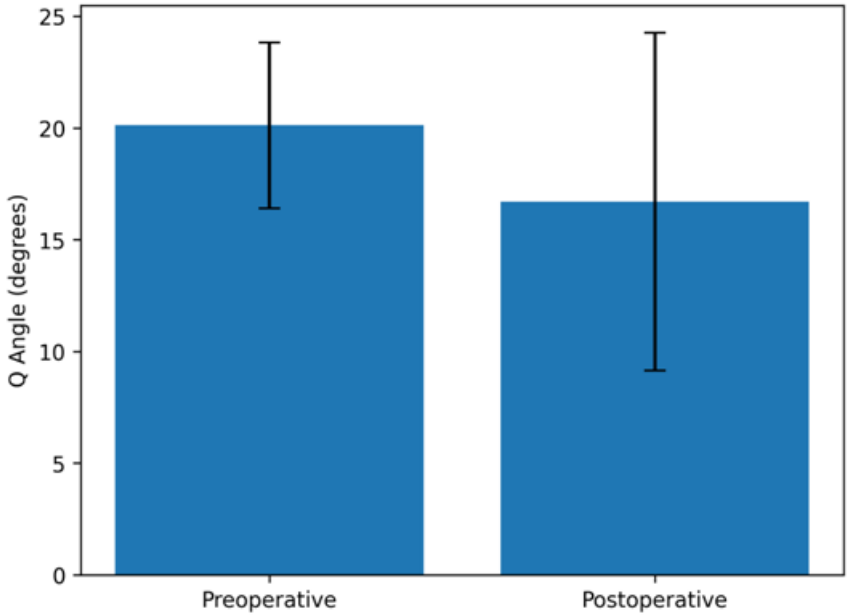

Figure 2: Q Angle before and after total knee arthroplasty

Table 3 demonstrates the longitudinal improvement in functional outcomes following total knee arthroplasty. Significant progressive enhancement was observed in Knee Society Scores (knee, functional, and combined) as well as Oxford Knee Score from the preoperative period to 3 months and 6 months postoperatively. The magnitude of improvement between baseline and final follow-up was substantial, with large effect sizes indicating strong clinical impact of surgical intervention. These findings confirm that correction of lower limb alignment following total knee arthroplasty was associated with marked pain relief, improved joint function, and enhanced patient mobility during early postoperative recovery.

Table 3: Functional Outcomes Over Time Following Total Knee Arthroplasty

Outcome measure	n (paired)	Preoperative (Mean ± SD)	3 Months (Mean ± SD)	6 Months (Mean ± SD)	Mean Change (Pre→6m)	% Change (Pre→6m)	Effect Size (Cohen's d, paired)
KSS – Knee	94	40.07 ± 6.74	77.44 ± 7.45	84.82 ± 7.22	44.68	111.5%	11.19
KSS – Function	94	36.04 ± 7.17	72.54 ± 9.18	79.94 ± 9.05	43.82	121.6%	6.46
KSS – Total	94	76.12 ± 13.90	149.98 ± 16.30	164.76 ± 15.86	88.50	116.3%	8.55
Oxford Knee Score (OKS)	94	18.56 ± 5.64	35.92 ± 8.85	40.48 ± 8.81	21.88	117.9%	3.07

KSS, Knee Society Score; OKS, Oxford Knee Score; SD, Standard Deviation; TKA, Total Knee Arthroplasty.

Figure 3 illustrates the progressive improvement in functional outcomes following total knee arthroplasty, demonstrating a sustained increase in combined Knee Society Score (KSS) and Oxford Knee Score (OKS) from the preoperative period to 3 months and 6 months postoperatively. The upward trend reflects significant enhancement in knee function, pain relief, and patient-reported mobility following alignment correction.

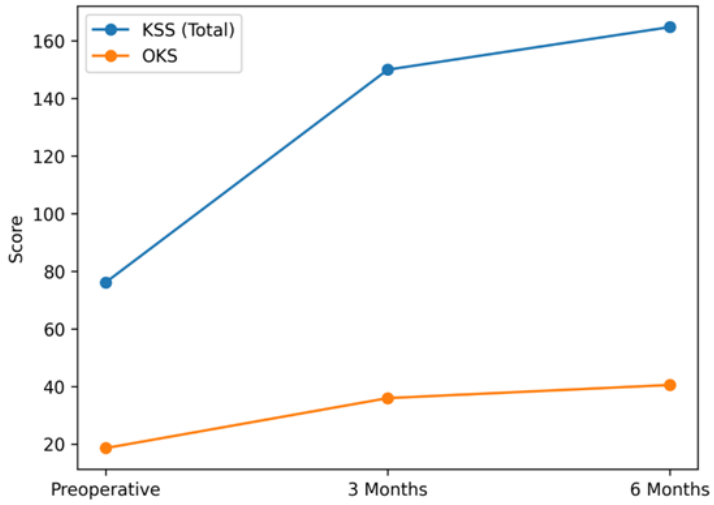

Figure 3: Functional outcome trend following total knee arthroplasty

Table 4 presents the correlation analysis between correction of lower limb alignment parameters and postoperative functional improvement following total knee arthroplasty. The analysis demonstrates a positive association between mechanical axis, anatomical axis, and Q angle correction with improvement in Knee Society Score and Oxford Knee Score. Greater restoration of limb alignment was associated with superior functional recovery, indicating that accurate correction of coronal alignment and extensor mechanism biomechanics contributes significantly to improved postoperative clinical outcomes.

Table 4: Correlation Between Alignment Correction and Functional Outcome Following Total Knee Arthroplasty

Variable	MA Correction	AA Correction	Q Correction	KSS Improvement	OKS Improvement
MA_Correction	1	0.971	0.396	0.245	-0.06
AA_Correction	0.971	1	0.567	0.36	-0.241
Q_Correction	0.396	0.567	1	0.678	-0.834
KSS_Improvement	0.245	0.36	0.678	1	-0.304
OKS_Improvement	-0.06	-0.241	-0.834	-0.304	1

MA, Mechanical Axis; AA, Anatomical Axis; Q angle, Quadriceps Angle; KSS, Knee Society Score; OKS, Oxford Knee Score; r, Pearson correlation coefficient; TKA, Total Knee Arthroplasty.

Table 5 presents the combined multivariable regression analysis evaluating the independent effect of alignment correction parameters on 6-month functional outcomes following total knee arthroplasty. Both surgeon-assessed (Knee Society Score) and patient-reported (Oxford Knee Score) outcomes were analyzed simultaneously. The model demonstrates that correction of lower limb alignment parameters, particularly Q angle and overall coronal alignment restoration, significantly contributed to postoperative functional improvement after adjusting for demographic factors and baseline clinical status.

These findings indicate that accurate biomechanical realignment plays an important role in determining early functional recovery and patient-perceived outcome following total knee arthroplasty.

Table 5: Combined Multivariable Regression Model Predicting 6-Month Functional Outcomes After TKA

Predictor	KSS Model Beta	SE	95% CI Low	95% CI High	p-value	OKS Model Beta	SE	95% CI Low	95% CI High	p-value
AA_Correction	-0.659592883	1.849319 59	-4.335918 55	3.016732 789	0.722214 07	-1.524266 971	0.753613 704	-3.022401 431	-0.026132 51	0.046220 156
Age	-0.244359 618	0.340144 27	-0.920544 06	0.431824 819	0.474458	-0.148115 232	0.134580 321	-0.415652 055	0.119421 592	0.274154 324
BMI	0.309041 617	0.579675 42	-0.843314 97	1.461398 203	0.595319 54	-0.026092 454	0.243351 539	-0.509859 302	0.457674 394	0.914863 202
Gender_Male	-1.449580 984	1.758930 7	-4.946219 48	2.047057 515	0.412147 62	-1.336329 655	0.725100 112	-2.777780 971	0.105121 66	0.068780 194
KSS_Pre	0.777976 738	0.330006 19	0.121946 15	1.434007 326	0.020670 4	-	-	-	-	-
MA_Correction	0.470953 197	1.676186 94	-2.861196 16	3.803102 551	0.779410 58	1.438941 748	0.686333 811	0.074555 289	2.803328 208	0.038969 843
Pre-op OKS	-	-	-	-	-	0.382524 36	0.272336 606	-0.158862 896	0.923911 615	0.163741 41
Q_Correction	1.231627 034	0.308049 29	0.619245 32	1.844008 753	0.000134 51	-0.872899 759	0.123244 446	-1.117901 608	-0.627897 91	3.6382 7E-10
const	110.8059 103	49.35325 23	12.69489 17	208.9169 288	0.027323 04	48.042532	15.03323 28	18.15745 428	77.92760 972	0.001950 945

KSS – Knee Society Score, OKS – Oxford Knee Score, MA – Mechanical Axis, AA – Anatomical Axis, Q angle – Quadriceps Angle, BMI – Body Mass Index, SE – Standard Error, CI – Confidence Interval, β (Beta) – Regression Coefficient, Adj. R^2 – Adjusted Coefficient of Determination

Discussion

Restoration of lower limb alignment remains a central biomechanical objective of total knee arthroplasty (TKA), as postoperative alignment directly influences joint loading characteristics, implant survivorship, and functional recovery. The present study comprehensively evaluated mechanical axis, anatomical axis, and Q angle simultaneously and demonstrated that multidimensional alignment restoration was independently associated with improved early postoperative functional outcomes. Unlike most previous investigations that primarily examined hip–knee–ankle alignment alone, the current study integrates coronal limb alignment with extensor mechanism biomechanics using multivariable modeling, thereby providing a broader assessment of determinants influencing postoperative recovery. Significant correction of mechanical axis deviation toward neutral alignment was observed following TKA in this cohort. Classical studies by Jeffery et al. and Fang et al. established that

postoperative malalignment increases mechanical stress and risk of implant failure, supporting restoration within ±3° of neutral alignment as a traditional surgical goal [3,4]. Our findings are consistent with these observations, as patients achieving greater mechanical axis correction demonstrated superior functional improvement. However, regression analysis indicated that mechanical axis correction alone was not the strongest determinant of postoperative outcome, suggesting that optimal recovery depends on interaction between multiple biomechanical parameters rather than isolated coronal alignment restoration.

Correction of the anatomical axis further contributed to restoration of physiological valgus alignment and improved femorotibial load distribution. Proper anatomical alignment maintains joint line orientation and soft tissue balance, both essential for normal knee kinematics [8]. Reduced postoperative variability in anatomical axis measurements in the present study reflects consistent surgical execution and effective deformity correction. Nevertheless, anatomical axis correction demonstrated a weaker independent association with functional recovery compared with extensor mechanism alignment parameters, emphasizing the multifactorial nature of postoperative function.

A key finding of this study was that Q angle correction emerged as a significant independent predictor of postoperative functional outcome. Multivariable regression analysis demonstrated that greater Q angle correction was associated with improved 6-month Knee Society Score and Oxford Knee Score, highlighting the clinical relevance of extensor mechanism realignment. Altered quadriceps force vectors in varus or valgus deformity contribute to abnormal patellar tracking and anterior knee pain, recognized causes of postoperative dissatisfaction following TKA[5].

Restoration of coronal alignment likely normalizes quadriceps pull and reduces patellofemoral contact stress, thereby improving both objective knee performance and patient-perceived function. Few clinical studies have incorporated Q angle correction within predictive outcome modeling, and this integrated assessment represents an important contribution of the present investigation.

Recent orthopedic literature has increasingly questioned the universal requirement for neutral mechanical alignment with the introduction of kinematic and patient-specific alignment strategies. Howell and colleagues reported favorable functional outcomes using individualized alignment approaches that preserve constitutional limb alignment [5]. Conversely, contemporary registry and meta-analytic data continue to demonstrate increased revision risk associated with substantial coronal malalignment beyond accepted thresholds[8]. The findings of the present study contribute to this ongoing debate by suggesting that while strict mechanical neutrality may not be universally necessary, meaningful correction of pathological deformity—particularly when accompanied by improved extensor mechanism alignment—remains strongly associated with early functional recovery.

An additional strength of this study is the simultaneous evaluation of surgeon-assessed and patient-reported outcomes. Previous studies have demonstrated discordance between radiographic alignment and patient satisfaction following TKA [7].

In the present analysis, alignment correction, particularly Q angle normalization, was associated with improvement in both Knee Society Score and Oxford Knee Score, suggesting that biomechanical restoration translates into clinically meaningful patient benefit.

Several limitations should be acknowledged. The study was conducted at a single center with relatively short-term follow-up, precluding assessment of long-term implant survivorship. Rotational alignment parameters and three-dimensional kinematic evaluation were not assessed. Radiographic measurements may be subject to observer-dependent variability, and interobserver reliability analysis was not performed. Furthermore, implant-specific factors and navigation-assisted techniques were not evaluated, which may influence alignment accuracy. These factors should be considered when interpreting the findings.

From a clinical perspective, the results suggest that successful TKA should extend beyond restoration of mechanical axis alignment alone. Comprehensive biomechanical correction—including anatomical alignment and optimization of extensor mechanism orientation—may represent a more meaningful determinant of postoperative recovery. Consideration of patellofemoral mechanics during surgical planning and component positioning may therefore improve functional outcomes and patient satisfaction.

Conclusion

In conclusion, total knee arthroplasty produced significant correction of mechanical axis, anatomical axis, and Q angle, and these alignment improvements were independently associated with enhanced early functional outcomes. The findings support a multidimensional alignment strategy integrating limb

alignment and extensor mechanism biomechanics to optimize postoperative recovery following TKA.

Ethics Statement: This study was conducted after obtaining approval from the Institutional Ethics Committee of [Name of Institution]. Ethical clearance was granted prior to initiation of the study (Approval No: ORTHO/2021/112). All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Declaration of Helsinki and its later amendments. Written informed consent was obtained from all participants prior to enrollment in the study. Patient confidentiality and anonymity were strictly maintained throughout data collection, analysis, and reporting.

Conflict of Interest: All authors declare that they have no financial relationships with any organizations that might have an interest in the submitted work.

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Author Contributions

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Data Availability: The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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