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Research Article

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Five-Year Outcomes of UKA Versus TKA in Elderly Patients With Severe Varus Deformity in Knee Osteoarthritis: The Modifying Effect of Preoperative Extensor Muscle Radiomics Quality

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Abstract

Background

The role of unicompartmental knee arthroplasty (UKA) in elderly patients with severe varus deformity in knee osteoarthritis remains controversial. Whether preoperative extensor muscle quality modifies the early functional advantage of UKA over total knee arthroplasty (TKA) has not been fully investigated.

Methods

This single-center retrospective cohort study included 176 elderly patients with medial compartment knee osteoarthritis and severe varus deformity (>15° and ≤20°) who underwent UKA (n = 81) or TKA (n = 95) between February 2016 and April 2019. Perioperative outcomes, complications, clinical scores, radiographic alignment parameters, and preoperative muscle quality were compared. Muscle quality was evaluated using conventional MRI-based measurements and an extensor radiomics score (Rad-score). Multivariable regression and procedure-by-Rad-score interaction analysis were performed.

Results

Compared with TKA, UKA was associated with less intraoperative blood loss, shorter operation time, smaller incision, and lower postoperative drainage volume (all $P < 0.001$). UKA showed superior early recovery at 1 month and 1 year. At 5 years, WOMAC remained slightly lower in the UKA group (9.4 ± 1.9 vs. 10.1 ± 1.6, $P = 0.010$), whereas VAS, HSS, and ROM were comparable between groups. Higher extensor Rad-score, indicating poorer muscle quality, was associated with lower early ROM and HSS scores and higher WOMAC scores. The interaction between surgical procedure and extensor Rad-score was significant for 1-month WOMAC ($\beta = 0.74$, 95% CI 0.06 to 1.42, $P = 0.032$), indicating that poorer extensor muscle quality attenuated the early WOMAC benefit of UKA relative to TKA.

Conclusions

In carefully selected elderly patients with severe varus medial knee osteoarthritis, UKA achieved comparable five-year clinical outcomes to TKA, with less surgical trauma and faster early recovery. Preoperative extensor muscle radiomics quality may help stratify recovery potential, guide individualized procedure selection, and identify patients who may benefit from intensified prehabilitation and early postoperative rehabilitation.

Keywords: UKA; TKA; severe varus deformity; knee OA; extensor muscle quality; MRI radiomics; Rad-score

Introduction

Knee osteoarthritis (OA) is a leading cause of chronic pain, disability, and impaired quality of life among older adults [1,2]. For patients with advanced disease who fail conservative management, knee arthroplasty remains an effective surgical treatment [3]. Total knee arthroplasty (TKA) has traditionally been regarded as the standard procedure for end-stage knee OA, but it involves more extensive bone and soft-tissue resection and may be associated with greater early functional inhibition in elderly patients.

Unicompartmental knee arthroplasty (UKA) is a bone- and ligament-preserving procedure that treats the diseased compartment while retaining native knee kinematics, cruciate-ligament function, and proprioceptive structures [4-6]. These features may promote faster early recovery than TKA in appropriately selected patients. However, conventional UKA indications have been cautious in patients with severe varus deformity, particularly when the deformity exceeds 15°, because residual malalignment may increase concerns regarding bearing wear, aseptic loosening, and progression of lateral compartment degeneration [7-9].

Existing studies evaluating UKA in large varus deformities have mainly focused on alignment correction, implant survival, and conventional functional outcomes [7-9]. Far less attention has been paid to patient-specific soft-tissue and muscle factors that may influence functional recovery. Therefore, simply asking whether severe varus deformity is an absolute contraindication may be insufficient; a more clinically relevant question is which selected patients can recover well after UKA despite a preoperative varus angle greater than 15°.

Beyond osseous alignment and compartment involvement, muscle quality is increasingly recognized as an important determinant of knee OA symptoms, postoperative recovery, and long-term function [10-14]. Quadriceps weakness, reduced cross-sectional area (CSA), and increased intramuscular adiposity may limit early motion, gait recovery, and patient-reported outcomes after knee arthroplasty. MRI-based radiomics may capture intramuscular tissue heterogeneity beyond simple CSA or fat fraction, and recent work suggests that thigh-muscle radiomic features are associated with knee OA development and progression [15].

However, no study has specifically examined whether preoperative extensor muscle radiomics quality modifies the early functional advantage of UKA over TKA in elderly patients with severe varus knee OA. This study therefore compared five-year clinical and radiographic outcomes between UKA and TKA in carefully selected elderly patients with severe varus deformity and incorporated preoperative muscle quality assessment, including an MRI-derived extensor Rad-score, to test whether muscle quality was associated with recovery and whether it modified procedure-related functional benefit.

Methods

Study design and patients

This single-center retrospective cohort study was conducted at Xuzhou Central Hospital and was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [16]. Consecutive elderly patients who underwent UKA or TKA for medial compartment knee OA between February 2016 and April 2019 were screened. The study protocol was approved by the Biomedical Research Ethics Committee of Xuzhou Central Hospital (approval number: XZXY-LK-20150318-0135) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all patients. Follow-up data were obtained from scheduled outpatient visits, radiographic review, electronic medical records, and telephone confirmation of complications or revision events when needed.

Initially, 102 UKA patients and 120 TKA patients were screened. After excluding 15 patients with incomplete preoperative or postoperative imaging data, 7 patients with ipsilateral total hip or ankle arthroplasty, and 12

patients with a history of lower-limb fracture surgery, 176 patients were included in the final analysis: 95 in the TKA group and 81 in the UKA group.

The inclusion criteria were as follows: age ≥60 years; minimum follow-up of 5 years; varus deformity >15° and ≤20°; medial compartment OA with bone-on-bone contact; intact or functionally competent anterior cruciate ligament and medial collateral ligament; normal or mild degeneration of the lateral and patellofemoral compartments; absence of lateral subluxation or marked trochlear groove abnormality; and failure of conservative treatment. For UKA candidates with varus deformity >15°, additional functional selection emphasized correctable deformity, flexion contracture <10°, no fixed extra-articular deformity >5°, preserved collateral-ligament stability, and intraoperative confirmation that the lateral compartment and patellofemoral joint were acceptable. The exclusion criteria were age <60 years, follow-up <5 years, inflammatory arthritis or multicompartmental OA, cruciate ligament absence or collateral ligament insufficiency, symptomatic patellofemoral arthritis, marked trochlear groove abnormality, and previous osteotomy or fracture surgery around the knee.

Surgical procedures and postoperative management

All operations were performed by the same experienced surgical team. TKA was performed through a standard anterior midline incision and medial parapatellar approach. After removal of residual menisci, cruciate ligaments, and osteophytes, femoral and tibial bone cuts were performed using standard instrumentation. Soft-tissue balancing and patellar management were performed as required. Cemented femoral and tibial components were implanted after confirmation of appropriate flexion-extension gaps and stability.

UKA was performed under the same anesthetic and positioning conditions. With the knee flexed at 90°, a medial parapatellar mini-incision of approximately 10-12 cm was used. The lateral compartment and cruciate ligaments were inspected intraoperatively. Medial osteophytes, synovium, and the medial meniscus were removed, and tibial and femoral bone preparation was completed using standard UKA instrumentation. Cemented components were implanted after trial reduction confirmed proper stability and alignment. Both groups received pulse lavage, routine drainage, layered closure, antibiotics, hemostasis, compression dressing, intermittent cold therapy within the first 24 hours, and standardized rehabilitation.

Clinical and radiographic assessments

Demographic variables, including age, sex, and body mass index (BMI), were collected. Perioperative variables included intraoperative blood loss, operation time, incision length, postoperative drainage volume, length of hospital stay, and complications. Clinical outcomes were assessed preoperatively and at 1 month, 1 year, and 5 years postoperatively using the visual analog scale (VAS) pain score, Hospital for Special Surgery (HSS) knee score, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score, and knee range of motion (ROM).

All patients underwent preoperative and 5-year postoperative weight-bearing full-length anteroposterior radiographs of both lower limbs and standard knee radiographs. Preoperative Rosenberg-view radiographs were routinely obtained. Two independent orthopedic surgeons measured the hip-knee-ankle angle (HKA), mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA), and joint line convergence angle (JLCA). HKA was recorded as an absolute mechanical-axis angle; for clinical interpretation, deviation from 180° was also considered as the varus angle. For example, an HKA of 162.2° indicates approximately 17.8° of varus deviation from neutral alignment.

Preoperative muscle quality assessment

Preoperative muscle quality was evaluated on knee MRI. In this cohort, all 176 patients had MRI images suitable for conventional muscle quality assessment. A radiomics subset of 146 patients was included in the Rad-score

analysis; 30 patients were excluded from radiomics modeling because of incomplete muscle coverage, motion artifacts, inconsistent sequence parameters, or inadequate signal-to-noise ratio. MRI and CT data were not mixed for Rad-score construction. If CT images were used as supportive sensitivity material, they were restricted to conventional CSA and fat infiltration measurements and were not incorporated into radiomics modeling.

Muscle segmentation was performed using a semi-automatic or manual approach by two observers who were blinded to the surgical procedure and clinical outcomes. To reduce measurement heterogeneity, the superior pole of the patella was used as the primary standardized segmentation level for conventional analysis. When complete thigh MRI was available, the distal 33% femoral level was used only for sensitivity assessment and was not mixed with the primary segmentation level. The primary regions included the extensor muscle group, mainly the quadriceps; the flexor muscle group, mainly the hamstrings; and auxiliary thigh muscles contributing to knee motion and stability. In the reproducibility subset, both observers performed repeated measurements; for the remaining cases, measurements were completed by a trained senior observer after calibration, and uncertain boundaries were adjudicated by consensus.

Conventional muscle quality variables included muscle CSA, intramuscular adipose tissue CSA (intra-MAT CSA), and fat infiltration percentage. Muscle CSA was calculated from the segmented ROI area. On T1-weighted or equivalent MRI sequences, intra-MAT CSA was identified using initial Otsu thresholding followed by manual correction [17]. Fat infiltration percentage was calculated as intra-MAT CSA divided by total muscle CSA multiplied by 100%. Raw CSA was used in the primary analysis, and CSA normalized by height squared ($CSA/height^2$) was used in sensitivity analysis.

For radiomics analysis, MRI images were resampled, normalized, bias-field corrected, and discretized before feature extraction, following the principles of the Image Biomarker Standardisation Initiative [18]. Morphological, first-order, and texture features were extracted, including gray-level co-occurrence matrix, gray-level run-length matrix, gray-level size-zone matrix, neighborhood gray-tone difference matrix, and gray-level dependence matrix features. Stable features with intraobserver and interobserver intraclass correlation coefficients (ICCs) >0.80 were retained [19]. Candidate features were reduced using minimum redundancy maximum relevance (mRMR) selection and least absolute shrinkage and selection operator (LASSO) regression [20,21]. The resulting extensor Rad-score was calculated as a weighted linear combination of selected radiomic features and was used as a continuous muscle-quality marker. A higher Rad-score indicated poorer extensor muscle quality. The median Rad-score was used only for descriptive stratified analysis, whereas the primary regression models treated Rad-score as a continuous variable.

Statistical analysis

Continuous variables are presented as mean ± standard deviation and were compared between groups using independent-samples t tests. Categorical variables are presented as numbers and percentages and were compared using the chi-square test or Fisher exact test, as appropriate. Repeated-measures analysis of variance was used for longitudinal within-group comparisons, with Bonferroni correction for post-hoc comparisons when appropriate. Separate multivariable linear regression models were constructed for each primary postoperative outcome, particularly 1-month HSS, ROM, WOMAC, and VAS outcomes. Pre-specified covariates were forced into multivariable models rather than selected by stepwise procedures. These covariates included age, sex, BMI, preoperative HKA, the corresponding preoperative functional score, surgical procedure, extensor Rad-score, and the pre-specified interaction term between surgical procedure and extensor Rad-score. Additional interactions were not included because the primary hypothesis focused on whether preoperative extensor muscle quality modified the procedure-related early recovery difference. Multicollinearity was assessed using the variance inflation factor (VIF), with VIF <5 indicating no major multicollinearity. Sensitivity analysis using CSA normalized by height squared was performed to test whether muscle-size findings were robust to body-size

normalization. No formal a priori sample-size calculation was performed because of the retrospective design. A two-sided P value <0.05 was considered statistically significant.

Results

Baseline characteristics and perioperative outcomes

A total of 176 patients were included, with 95 in the TKA group and 81 in the UKA group. Baseline age, sex distribution, and BMI were comparable between groups (Table 1). Compared with TKA, UKA was associated with significantly less intraoperative blood loss, shorter operation time, smaller incision, and lower postoperative drainage volume (all $P < 0.001$). Length of hospital stay did not differ significantly between groups (Table 2).

Clinical outcomes

Preoperative VAS, HSS, WOMAC, and ROM did not differ significantly between groups. Both procedures produced significant postoperative improvements in pain and functional scores. At 1 month and 1 year postoperatively, the UKA group had higher HSS and ROM values and lower WOMAC scores than the TKA group. At 1 month, VAS was also lower in the UKA group. At 5 years, WOMAC remained slightly lower in the UKA group ($P = 0.010$), whereas VAS, HSS, and ROM were comparable between groups (Table 3; Figures 1 and 2).

Complications and revision

Complications were uncommon in both groups. In the TKA group, there were two cases of incisional fat liquefaction, two superficial wound infections, and one intermuscular venous thrombosis. In the UKA group, there were two cases of incisional fat liquefaction and one superficial wound infection. All complications improved after dressing changes, antibiotics, or anticoagulation as appropriate. No prosthetic loosening, periprosthetic infection, tibial plateau fracture, or revision was observed during follow-up (Table 4).

Radiographic outcomes

Preoperative HKA, mLDFA, MPTA, and JLCA were comparable between groups. Expressed as deviation from a neutral 180° mechanical axis, the mean preoperative varus angle was approximately 17.8° in the TKA group and 17.6° in the UKA group. At 5 years, TKA achieved greater correction of HKA, mLDFA, and MPTA and lower JLCA than UKA, indicating more complete correction of lower-limb alignment and joint-line convergence. However, this radiographic advantage did not correspond to superior five-year VAS, HSS, or ROM outcomes (Table 5; Figures 3 and 4).

Muscle quality and functional recovery

Preoperative muscle quality variables were balanced between the TKA and UKA groups (Table 6). Conventional muscle measures were available in all 176 patients, whereas the radiomics-based extensor Rad-score was available in 146 patients. Reproducibility analysis in 30 randomly selected patients showed good-to-excellent intraobserver and interobserver agreement for muscle segmentation and Rad-score assessment, with ICCs ranging from 0.82 to 0.96 (Supplementary Table S1).

Correlation analysis showed that extensor muscle quality was consistently associated with postoperative functional recovery. Greater extensor CSA was positively correlated with 1-month ROM and 1-year HSS and negatively correlated with 5-year WOMAC. Higher extensor fat infiltration was associated with lower 1-month ROM and higher 1-month WOMAC. Higher extensor Rad-score, indicating poorer muscle quality, was negatively correlated with 1-month HSS and ROM and positively correlated with 1-month WOMAC (Table 7).

After adjustment for age, sex, BMI, preoperative HKA, the corresponding preoperative outcome, and surgical procedure, UKA remained independently associated with better 1-month HSS, ROM, and WOMAC. Higher extensor Rad-score remained independently associated with poorer 1-month HSS, ROM, and WOMAC. The interaction between UKA and extensor Rad-score was significant for 1-month WOMAC ($\beta = 0.74$, 95% CI 0.06 to 1.42, $P = 0.032$), suggesting that poorer extensor muscle quality weakened the early WOMAC benefit of UKA compared with TKA (Table 8; Figure 5).

When patients were stratified by the median extensor Rad-score (-0.02), UKA showed an early functional advantage over TKA in both muscle-quality strata. However, the magnitude of the benefit was greater in the better muscle-quality subgroup than in the poorer muscle-quality subgroup. In the better muscle-quality subgroup, the 1-month HSS advantage of UKA over TKA was 5.3 points and the WOMAC advantage was 5.7 points. In the poorer muscle-quality subgroup, the corresponding advantages were 3.5 points and 3.6 points, respectively, supporting the presence of effect modification by preoperative extensor muscle quality.

Discussion

This study provides two clinically relevant findings. First, in carefully selected elderly patients with severe varus medial knee OA, UKA achieved faster early recovery and comparable mid-term clinical outcomes to TKA despite less complete mechanical-axis correction. Second, and more importantly, preoperative extensor muscle radiomics quality modified early recovery: higher extensor Rad-score was associated with poorer 1-month functional outcomes and attenuated the early WOMAC benefit of UKA. This suggests that procedure selection and rehabilitation planning should consider not only bone alignment and compartment involvement, but also preoperative muscle reserve.

The interaction between surgical procedure and extensor Rad-score is the main novel finding of this study. Conventional muscle CSA provides useful information about muscle size, but it may not fully capture tissue composition. Intramuscular fat and radiomic heterogeneity may reflect non-contractile tissue replacement, fibrosis, edema, and microstructural alteration [13-15]. The observed associations between higher extensor Rad-score and poorer early ROM, HSS, and WOMAC support the idea that muscle quality contains clinically relevant information beyond alignment or procedure type. Importantly, a poor Rad-score did not necessarily make UKA unsuitable; rather, it identified patients in whom the early functional advantage of UKA was smaller and who may require more intensive perioperative rehabilitation.

The early advantage of UKA remains biologically plausible. Compared with TKA, UKA preserves more bone stock, native ligaments, cruciate-ligament function, and proprioceptive structures [4-6]. These features may reduce soft-tissue disruption, postoperative pain, inflammation, and quadriceps inhibition, thereby facilitating earlier active motion and weight-bearing training. Our findings are consistent with previous studies reporting faster early recovery after UKA in selected patients [5,6].

TKA produced more complete correction of HKA, mLDFA, MPTA, and JLCA in this study. Nevertheless, superior radiographic alignment did not lead to better five-year VAS, HSS, or ROM. This suggests that postoperative function is not determined solely by the magnitude of mechanical-axis correction. Preservation of native knee kinematics, cruciate-ligament function, proprioception, neuromuscular control, pain adaptation, and rehabilitation tolerance may partly offset the mechanical disadvantage of mild residual varus after UKA when the joint remains stable and disease is compartmentalized.

Severe varus deformity has traditionally raised concern for UKA because residual malalignment may increase medial compartment overload, implant wear, and loosening [7-9]. The present findings should not be interpreted as unrestricted expansion of UKA indications. Rather, they support UKA only in carefully selected patients with medial compartment disease, preserved cruciate and collateral ligament function, correctable deformity, limited

flexion contracture, and no substantial lateral or patellofemoral disease. Under these conditions, selected patients with varus deformity between 15° and 20° may still achieve satisfactory mid-term outcomes.

These findings have practical implications. Preoperative extensor muscle quality assessment may help refine counseling, identify patients at risk for slower recovery, and guide prehabilitation. For anatomically suitable UKA candidates with poor extensor quality, the present results do not support rejecting UKA solely because the early advantage may be smaller. Instead, such patients may benefit from a structured 4- to 6-week prehabilitation program emphasizing quadriceps isometric and progressive resistance exercises, neuromuscular activation training, gait and balance training, nutritional optimization when sarcopenia or malnutrition is suspected, and early postoperative neuromuscular electrical stimulation when appropriate [10-12].

In future predictive models, muscle quality should be considered alongside age, BMI, preoperative alignment, baseline function, ligament status, and compartment involvement. A combined model integrating anatomical suitability and muscle radiomics quality may be more useful than a procedure-only comparison for individualized surgical decision-making.

Limitations

This study has several limitations. First, it was a single-center retrospective study, and selection bias related to surgeon preference, patient preference, baseline activity level, and radiographic disease pattern cannot be fully excluded. Second, all operations were performed by a single experienced surgical team; therefore, the findings may not be directly generalizable to lower-volume centers or surgeons early in the UKA learning curve. Third, the follow-up duration of 5 years is adequate for mid-term clinical evaluation but insufficient to fully assess long-term UKA revision risks, including polyethylene wear, lateral compartment OA progression, tibial component loosening, and delayed instability.

Fourth, muscle quality was assessed preoperatively only, and no standardized postoperative MRI was available to evaluate dynamic changes in muscle CSA, fat infiltration, or Rad-score after arthroplasty. Fifth, this study did not include objective muscle function tests, such as isokinetic strength testing, electromyography, gait analysis, or balance testing; therefore, imaging-based muscle quality could not be directly linked to physiological muscle performance. Sixth, radiomics analysis was performed in an internal subset only and requires consistent image acquisition, segmentation, feature extraction, and external validation before clinical use. Finally, although the regression models adjusted for major clinical and radiographic variables, residual confounding remains possible.

Conclusions

In carefully selected elderly patients with severe varus medial knee OA, UKA provided comparable five-year VAS, HSS, and ROM outcomes to TKA and was associated with less surgical trauma and faster early recovery; 5-year WOMAC remained slightly lower after UKA. TKA achieved more complete radiographic alignment correction, but this did not translate into superior mid-term clinical function. Preoperative extensor muscle quality, particularly MRI-derived extensor Rad-score, was associated with early postoperative recovery and modified the early WOMAC benefit of UKA. Incorporating muscle quality assessment into surgical decision-making may support more individualized procedure selection and targeted perioperative rehabilitation planning.

Abbreviations

BMI, body mass index; CI, confidence interval; CSA, cross-sectional area; CT, computed tomography; HKA, hip-knee-ankle angle; HSS, Hospital for Special Surgery knee score; ICC, intraclass correlation coefficient;

intra-MAT, intramuscular adipose tissue; JLCA, joint line convergence angle; LASSO, least absolute shrinkage and selection operator; mLDFA, mechanical lateral distal femoral angle; MPTA, medial proximal tibial angle; MRI, magnetic resonance imaging; mRMR, minimum redundancy maximum relevance; NMES, neuromuscular electrical stimulation; OA, osteoarthritis; Rad-score, radiomics score; ROI, region of interest; ROM, range of motion; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty; VAS, visual analog scale; VIF, variance inflation factor; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Biomedical Research Ethics Committee of Xuzhou Central Hospital (Approval No. XZXY-LK-20150318-0135). All participants provided written informed consent. Patient privacy and data confidentiality were protected throughout the study.

Consent for publication

Written consent for publication of anonymized clinical and radiographic data was obtained from the patients whose images are shown.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

X.Y.Z. contributed to study design, data collection, statistical analysis, and manuscript drafting. J.S., P.S., G.J., Z.X., Y.X., H.Z., and M.H. contributed to surgical treatment, image measurement, data interpretation, and manuscript revision. C.M. supervised the study and revised the manuscript critically. All authors read and approved the final manuscript. Please confirm the author initials and contribution details before submission.

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Table 1. Baseline characteristics of the study population

Variable	TKA (n = 95)	UKA (n = 81)	*P* value
Age, years	69.9 ± 4.8	70.3 ± 4.7	0.578
Sex, male/female	43/52	34/47	0.775
BMI, kg/m²	26.1 ± 3.7	26.2 ± 4.6	0.875

Note: Data are presented as mean ± standard deviation or number of patients. BMI, body mass index.

Table 2. Comparison of perioperative outcomes between the two groups

Variable	TKA (n = 95)	UKA (n = 81)	*P* value
Intraoperative blood loss, mL	166.1 ± 25.4	130.7 ± 21.3	<0.001
Operation time, min	101.6 ± 16.2	84.0 ± 12.3	<0.001
Incision length, cm	13.0 ± 1.1	8.5 ± 0.8	<0.001
Postoperative drainage volume, mL	199.5 ± 26.1	182.6 ± 28.8	<0.001
Length of hospital stay, days	6.2 ± 0.9	6.0 ± 0.6	0.081

Note: Data are presented as mean ± standard deviation.

Table 3. Comparison of clinical functional outcomes at different follow-up time points

Outcome	Time point	TKA (n = 95)	UKA (n = 81)	*P* value
ROM	Preoperative	93.0 ± 10.1	94.0 ± 9.5	0.500
ROM	1 month postoperatively	100.7 ± 5.9	105.8 ± 5.0	<0.001
ROM	1 year postoperatively	114.3 ± 2.6	118.1 ± 5.3	<0.001
ROM	5 years postoperatively	118.4 ± 8.0	119.0 ± 4.5	0.533
VAS	Preoperative	6.8 ± 1.0	6.6 ± 0.9	0.165
VAS	1 month postoperatively	3.6 ± 0.7	2.7 ± 0.7	<0.001
VAS	1 year postoperatively	0.9 ± 0.7	1.0 ± 0.7	0.346
VAS	5 years postoperatively	0.4 ± 0.5	0.3 ± 0.5	0.188
HSS	Preoperative	38.8 ± 4.7	39.4 ± 5.5	0.442
HSS	1 month postoperatively	79.3 ± 2.3	83.8 ± 3.3	<0.001
HSS	1 year postoperatively	84.0 ± 2.8	87.9 ± 3.0	<0.001
HSS	5 years postoperatively	93.2 ± 2.3	93.6 ± 3.0	0.329
WOMAC	Preoperative	50.1 ± 4.5	49.3 ± 4.1	0.219
WOMAC	1 month postoperatively	31.1 ± 3.3	26.2 ± 2.4	<0.001
WOMAC	1 year postoperatively	15.2 ± 2.2	12.2 ± 2.1	<0.001
WOMAC	5 years postoperatively	10.1 ± 1.6	9.4 ± 1.9	0.010

Note: ROM, range of motion; VAS, visual analog scale; HSS, Hospital for Special Surgery knee score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index. Between-group comparisons were performed using independent-samples t tests; within-group longitudinal comparisons were performed using repeated-measures analysis of variance with Bonferroni correction when appropriate. At 5 years, WOMAC remained statistically lower in the UKA group, whereas VAS, HSS, and ROM were comparable.

Table 4. Comparison of postoperative complications between the two groups

Complication	TKA (n = 95)	UKA (n = 81)	*P* value
Overall complications	5 (5.3%)	3 (3.7%)	0.374
Incisional fat liquefaction	2 (2.1%)	2 (2.5%)	
Superficial wound infection	2 (2.1%)	1 (1.2%)	
Intermuscular venous thrombosis	1 (1.1%)	0 (0%)	

Note: Data are presented as number of patients (percentage). Fisher exact test was used because of the low number of events. No revision, prosthetic loosening, periprosthetic infection, or tibial plateau fracture was observed during follow-up.

Table 5. Comparison of radiographic parameters preoperatively and at 5 years postoperatively

Radiographic parameter	Time point	TKA (n = 95)	UKA (n = 81)	*P* value
HKA	Preoperative	162.2 ± 1.2	162.4 ± 1.3	0.294
HKA	5 years postoperatively	179.6 ± 1.3	176.0 ± 1.1	<0.001
mLDFA	Preoperative	97.7 ± 2.2	97.4 ± 1.7	0.309
mLDFA	5 years postoperatively	89.3 ± 1.7	87.4 ± 1.8	<0.001
MPTA	Preoperative	80.0 ± 1.8	79.5 ± 1.9	0.076
MPTA	5 years postoperatively	89.8 ± 1.3	86.2 ± 2.2	<0.001
JLCA	Preoperative	7.5 ± 1.8	7.6 ± 1.7	0.705
JLCA	5 years postoperatively	1.2 ± 0.8	3.2 ± 1.0	<0.001

Note: HKA, hip-knee-ankle angle; mLDFA, mechanical lateral distal femoral angle; MPTA, medial proximal tibial angle; JLCA, joint line convergence angle. HKA is reported as an absolute mechanical-axis angle; varus deviation can be interpreted as the deviation from 180°.

Table 6. Comparison of preoperative muscle quality parameters between the two groups

Muscle quality parameter	TKA (n = 95)	UKA (n = 81)	*P* value
Extensor CSA, cm²	48.2 ± 7.6	49.1 ± 7.3	0.425
Flexor CSA, cm²	30.5 ± 5.4	31.0 ± 5.2	0.533
Auxiliary muscle CSA, cm²	17.8 ± 3.1	18.0 ± 3.3	0.681
Extensor intra-MAT CSA, cm²	5.8 ± 1.9	5.6 ± 1.8	0.475
Extensor fat infiltration, %	12.3 ± 3.7	11.8 ± 3.5	0.359
Extensor Rad-score (radiomics subset)	0.03 ± 0.86	-0.05 ± 0.82	0.529
Extensor CSA/height², cm²/m² (sensitivity analysis)	17.0 ± 2.7	17.4 ± 2.6	0.319

Note: CSA, cross-sectional area; intra-MAT, intramuscular adipose tissue; Rad-score, radiomic signature score. A higher Rad-score indicates poorer muscle quality. Raw CSA was used in the main analysis, whereas CSA/height² was used only in the sensitivity analysis. Rad-score was available in the radiomics subset of 146 patients (TKA n = 77, UKA n = 69). Conventional muscle quality measurements were available in all 176 patients.

Table 7. Correlation between preoperative muscle quality and postoperative functional outcomes

Muscle quality parameter	Postoperative outcome	r	*P* value
Extensor CSA	1-month postoperative ROM	0.31	<0.001
Extensor CSA	1-year postoperative HSS	0.28	<0.001
Extensor CSA	5-year postoperative WOMAC	-0.24	0.001
Extensor fat infiltration	1-month postoperative ROM	-0.35	<0.001
Extensor fat infiltration	1-month postoperative WOMAC	0.33	<0.001
Extensor Rad-score	1-month postoperative HSS	-0.38	<0.001
Extensor Rad-score	1-month postoperative ROM	-0.41	<0.001
Extensor Rad-score	1-month postoperative WOMAC	0.39	<0.001

Note: ROM, range of motion; HSS, Hospital for Special Surgery knee score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index. Only extensor muscle-quality variables most relevant to the primary hypothesis are shown.

Table 8. Multivariable regression analysis after inclusion of muscle quality parameters

Dependent variable	Independent variable	*β*	95% *CI*	*P* value
1-month postoperative HSS	UKA vs. TKA	3.56	2.61 to 4.51	<0.001
1-month postoperative HSS	Extensor Rad-score	-1.21	-1.78 to -0.64	<0.001
1-month postoperative ROM	UKA vs. TKA	4.38	2.91 to 5.85	<0.001
1-month postoperative ROM	Extensor Rad-score	-2.15	-3.01 to -1.29	<0.001
1-month postoperative WOMAC	UKA vs. TKA	-4.18	-5.03 to -3.33	<0.001
1-month postoperative WOMAC	Extensor Rad-score	1.62	1.04 to 2.20	<0.001
1-month postoperative WOMAC	UKA × extensor Rad-score	0.74	0.06 to 1.42	0.032
5-year postoperative WOMAC	UKA vs. TKA	-0.61	-1.10 to -0.12	0.015
5-year postoperative WOMAC	Extensor Rad-score	0.38	0.05 to 0.71	0.024

Note: Models were adjusted for age, sex, BMI, preoperative HKA, the corresponding preoperative outcome, and surgical procedure. *β* is the unstandardized coefficient. A higher Rad-score indicates poorer muscle quality. VIF range, 1.08-2.31. The UKA × extensor Rad-score interaction is visualized in Figure 5.

Supplementary Table S1. Reproducibility assessment of muscle quality parameters in 30 randomly selected patients

Parameter	Intraobserver ICC	Interobserver ICC	Interpretation
Extensor CSA	0.96	0.94	Excellent
Flexor CSA	0.95	0.93	Excellent
Auxiliary muscle CSA	0.94	0.92	Excellent
Extensor intra-MAT CSA	0.91	0.89	Good
Extensor fat infiltration	0.90	0.88	Good
Extensor Rad-score	0.85	0.82	Good

Note: ICC >0.80 was defined as good reproducibility.

Figures

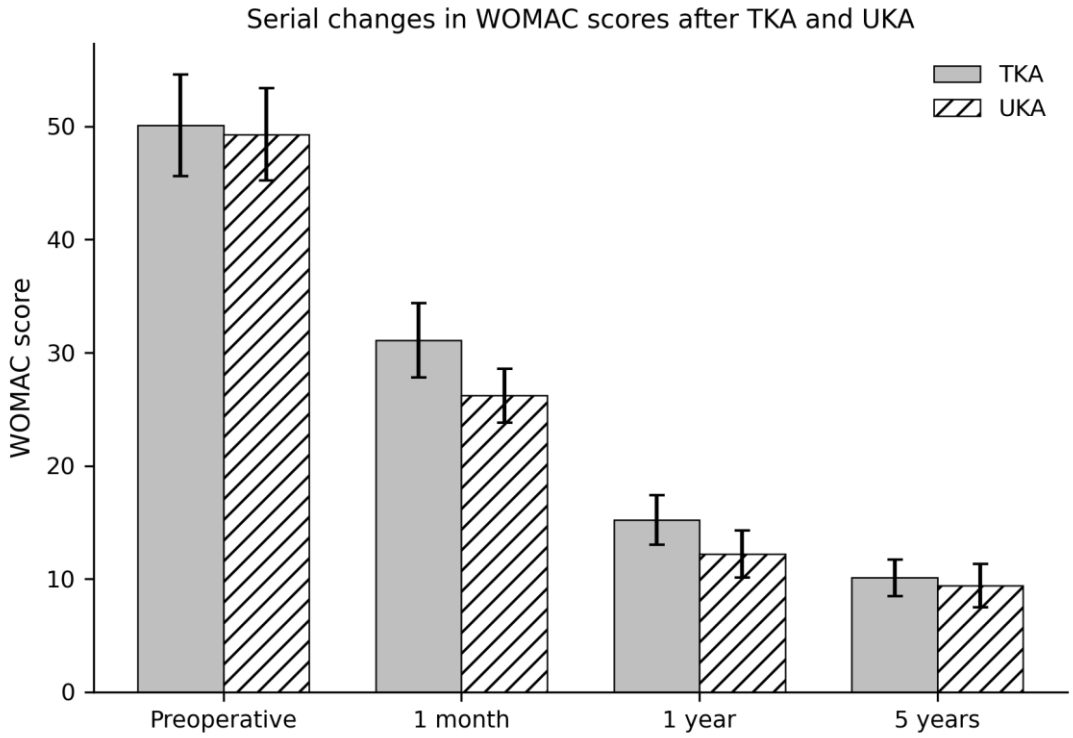


Figure 1. Serial changes in WOMAC scores after TKA and UKA. WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.

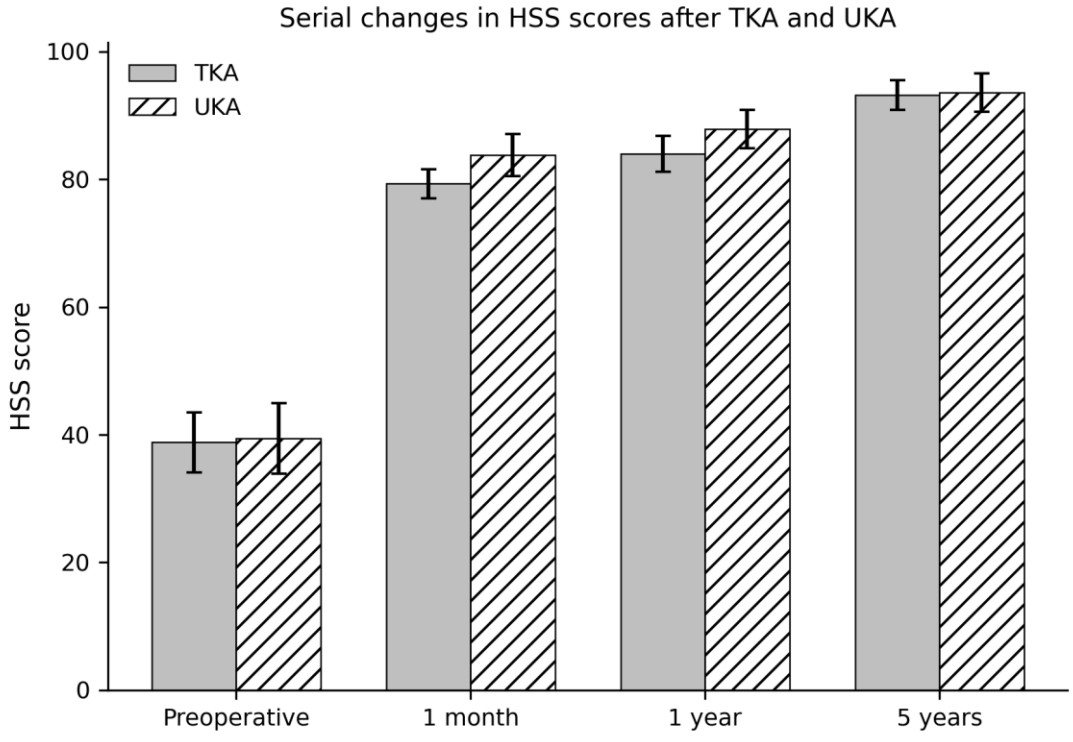


Figure 2. Serial changes in HSS scores after TKA and UKA. HSS, Hospital for Special Surgery knee score; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.

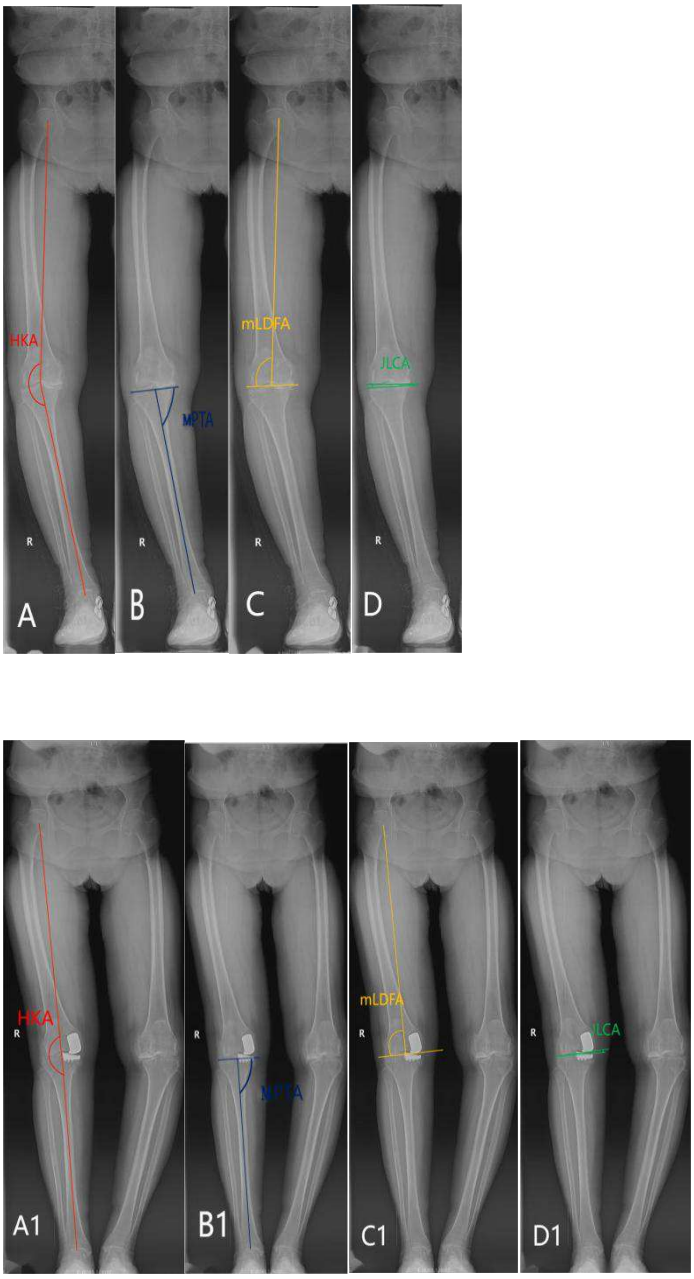


Figure 3. Representative radiographs of a patient with severe varus deformity of the right knee who underwent UKA. Preoperative radiographs (A-D) and 5-year postoperative radiographs (A1-D1) show limb alignment measurements and a well-positioned unicompartmental prosthesis.

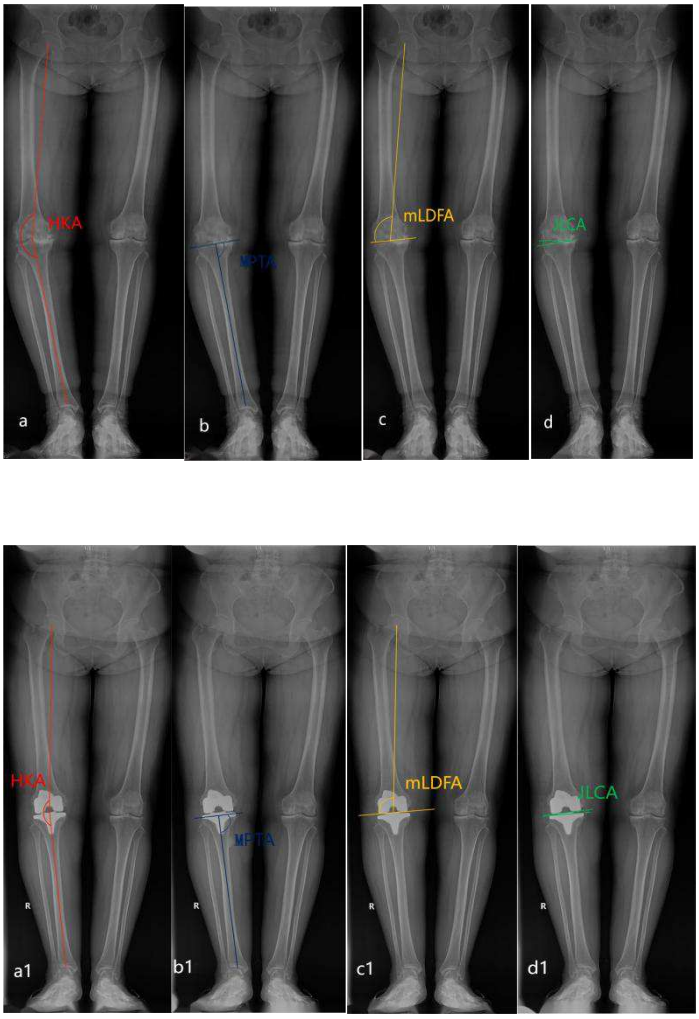


Figure 4. Representative radiographs of a patient with severe varus deformity of the right knee who underwent TKA. Preoperative radiographs (a-d) and 5-year postoperative radiographs (a1-d1) show limb alignment measurements and a well-positioned total knee prosthesis.

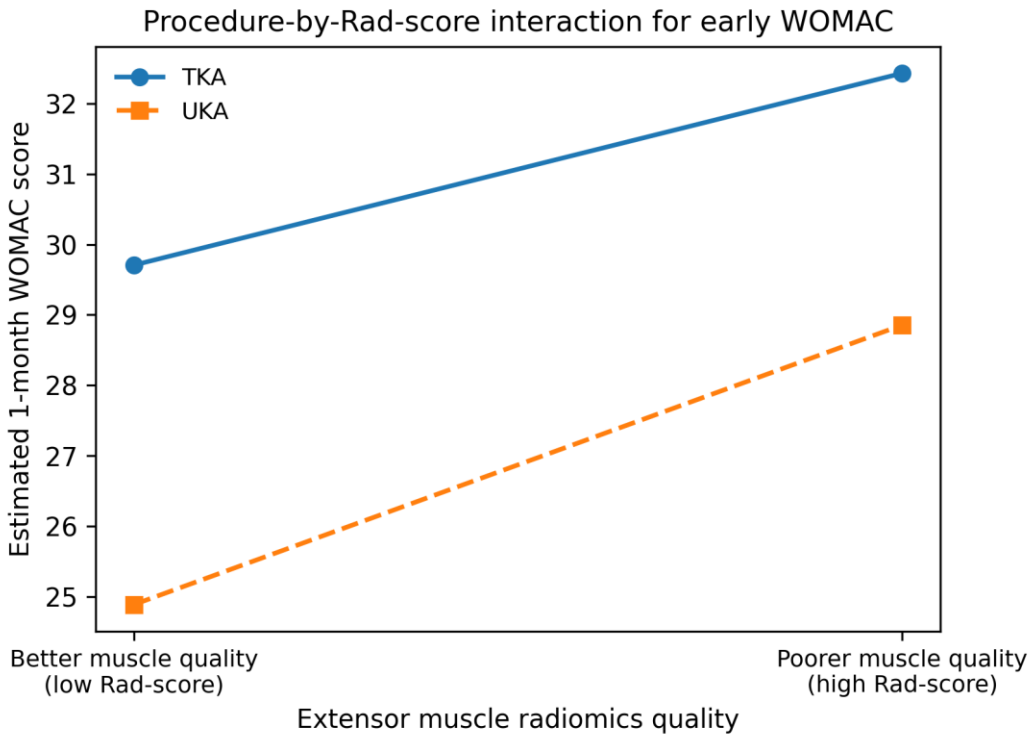
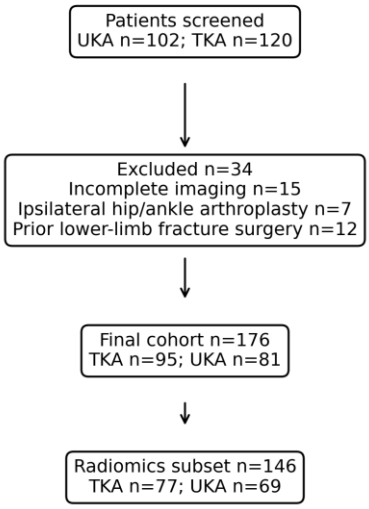


Figure 5. Model-estimated interaction between surgical procedure and extensor Rad-score for 1-month WOMAC. A higher Rad-score indicates poorer extensor muscle quality. The smaller vertical separation between UKA and TKA at higher Rad-score values illustrates attenuation of the early WOMAC advantage of UKA in patients with poorer extensor muscle quality.



Supplementary Figure S1. Patient selection flow diagram and radiomics subset. UKA, unicompartmental knee arthroplasty; TKA, total knee arthroplasty.