

Robotic-assisted surgery has less soft tissue damage than traditional total knee arthroplasty, with better early recovery and prosthesis placement

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Abstract

Objective

Robot-assisted total knee arthroplasty (TKA) has the potential to improve intraoperative osteotomy accuracy; however, clinical data on the Hong-Hu robotic system remain limited. This study aimed to compare the safety, accuracy, and early to mid-term outcomes between conventional TKA (CO-TKA) and Hong-Hu robot-assisted TKA (RA-TKA).

Methods

This retrospective cohort study included 161 patients who underwent primary unilateral TKA between December 2022 and December 2023: 76 in the RA-TKA group and 85 in the CO-TKA group. Intraoperative parameters included operative time, intraoperative blood loss, perioperative hemoglobin change, and soft tissue injury severity (graded using the modified Hampp classification). Radiographic outcomes included the hip-knee-ankle angle (HKA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA), sagittal tibial component angle (sTCA), and sagittal femoral component angle (sFCA). Clinical outcomes were assessed using the Oxford Knee Score (OKS), Knee Society Score (KSS), and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) at 3 and 6 months postoperatively. Daily visual analog scale (VAS) pain scores and active knee range of motion (ROM) were recorded during the first postoperative week. Postoperative complications were documented throughout the 6-month follow-up period.

Results

Compared with CO-TKA, Hong-hu robot-assisted TKA was associated with numerically lower intraoperative blood loss ($P = 0.09$) and perioperative hemoglobin decline ($P < 0.001$), less severe soft tissue injury (medial collateral ligament [MCL], $P = 0.013$; popliteal tendon, $P = 0.003$), and more accurate tibial osteotomy and prosthesis positioning (HKA, $P = 0.027$; mLDFA, $P = 0.015$; mMPTA, $P = 0.046$; sTCA, $P = 0.026$; sFCA, $P = 0.028$). Early postoperative recovery was superior in the RA-TKA group, with lower VAS pain scores ($P < 0.001$) and greater knee ROM ($P < 0.001$) during the first postoperative week. However, no significant between-group differences were observed in operative time ($P = 0.30$), lower extremity alignment correction rate (97.4% vs. 92.9%, $P = 0.35$), or mid-term functional scores at 3 months (OKS, $P = 0.33$; KSS-K, $P = 0.26$; KSS-F, $P = 0.07$; WOMAC, $P = 0.24$). At 6 months, the RA-TKA group demonstrated a significantly higher KSS-K score (95.2 ± 8.6 vs. 89.8 ± 9.3 , $P = 0.03$), whereas other functional scores remained comparable.

Introduction

Osteoarthritis (OA) is a prevalent degenerative joint disease characterized by progressive articular cartilage loss, subchondral bone sclerosis, osteophyte formation, synovial inflammation, and ligamentous calcification, predominantly affecting the weight-bearing hip and knee joints^[1]. The Global Burden of Disease Study 2021 identified knee osteoarthritis (KOA) as the most common manifestation of OA, with its incidence increasing by 56.9% between 1990 and 2020, establishing KOA as a major contributor to global disability^[2]. In end-stage KOA, total knee arthroplasty (TKA) is the standard surgical intervention to alleviate pain and restore function. Nevertheless, patient-reported outcomes remain variable, with satisfaction rates ranging from 75% to 89%^[3]. The primary goals of TKA include restoration of neutral mechanical alignment, preservation of the joint line, balancing of the flexion-extension gap, and maintenance of a physiological Q-angle to ensure appropriate patellar tracking. Consequently, the precision of intraoperative osteotomy is a critical determinant of procedural success^[4]. Conventional TKA (CO-TKA) relies on anatomical landmarks and manual cutting guides for intraoperative osteotomy. However, this approach is inherently dependent on surgeon experience, which may result in suboptimal osteotomy accuracy and increased iatrogenic soft tissue injury. To address these limitations, robotic-assisted TKA was developed. The ROBODOC system (Curexo Technology, Fremont, CA, USA) became the first robotic platform applied in TKA in 1992. However, early robotic systems were limited by technical complexity, prolonged operative times, and insufficient versatility, restricting their widespread adoption^[5]. Advances in robotic technology have led to substantial refinements in orthopaedic robotic systems, with contemporary platforms demonstrating improved clinical applicability. Currently available robotic systems for joint arthroplasty include the ROBODOC (Curexo Technology, Sacramento, CA, USA)^[6], iBlock robotic cutting guide (OMNIlife Science, Raynham, MA, USA)^[7], Navio PFS (Smith & Nephew, Watford, UK)^[7] and MAKO Robotic Arm Interactive System (Stryker, Mahwah, NJ, USA)^[8].

In TKA, robotic systems enhance implant positioning and alignment accuracy, facilitate optimized component placement based on soft tissue balance and tension, and enable intraoperative assessment of flexion-extension gaps, joint stability, and lower extremity alignment. The surgeon can thereby make real-time modifications to osteotomy plans, adjust prosthesis position, and perform soft tissue micro-adjustments to achieve satisfactory bone coverage, optimal prosthesis positioning, physiological knee kinematics, and neutral lower extremity alignment, ultimately improving clinical outcomes^[9–11]. Between 2015 and 2020, the annual volume of RA-TKA in the United States increased more than sixfold. In a survey of American Association of Hip and Knee Surgeons (AAHKS) members, 73.1% of surgeons using robotic assistance cited superior precision and optimized intraoperative soft tissue balancing as the primary motivations for adoption^[12]. However, a meta-analysis by Mason et al.^[13] reported that 9% of patients still exhibited lower extremity mechanical axis deviation exceeding 3° following RA-TKA. The clinical benefits of RA-TKA remain debated.

The Hong-Hu Joint Robot (Suzhou MicroPort OrthoBot Co., Ltd., Shanghai, China) is a semi-active robotic system that enables preoperative surgical planning based on patient-specific CT data, automatically generating a three-dimensional surgical simulation for intraoperative execution. Theoretically, adherence to the preoperative plan should enhance osteotomy precision and improve

clinical outcomes. However, clinical evidence supporting the Hong-Hu system remains limited. The present study aimed to evaluate the safety, accuracy, and efficacy of Hong-Hu RA-TKA by comparing early to mid-term outcomes with those of CO-TKA.

Materials and Methods

1. Patient Selection

This retrospective cohort study was conducted at Clinical data of consecutive patients who underwent primary unilateral TKA in Gansu Provincial People's Hospital from December 2022 to December 2023 were retrospectively reviewed. Patients were allocated to either the CO-TKA group or the RA-TKA group based on the surgical approach selected by the patient and the attending surgeon after thorough informed consent.

Inclusion criteria: (1) age ≥ 18 years, regardless of sex; (2) primary unilateral TKA; (3) radiographic diagnosis of Kellgren-Lawrence grade IV knee osteoarthritis; (4) minimum 6-month postoperative follow-up.

Exclusion criteria: (1) significant coronal plane deformity $> 15^\circ$ (varus or valgus); (2) preoperative deep vein thrombosis of the affected limb; (3) history of prior knee surgery, trauma, or fracture compromising study evaluation or surgical safety; (4) incomplete follow-up data.

2. Surgical procedure

RA-TKA group:

Preoperative planning: Preoperative CT data encompassing the hip, knee, and ankle joints were imported into the Hong-Hu robotic planning system to generate a three-dimensional full-length lower extremity model. The osteotomy plan and prosthesis size were determined preoperatively, and the final surgical plan was generated (Fig. 1). Intraoperative procedure: The robotic arm and optical navigation system were connected, and patient identity and preoperative planning were verified prior to incision. After induction of satisfactory anesthesia, the patient was placed in the supine position. A lateral support was positioned to stabilize the affected limb, and a pneumatic tourniquet was applied at the proximal thigh. The limb was prepared and draped in standard sterile fashion, elevated for exsanguination, and an Esmarch bandage was applied. The tourniquet was inflated to 300 mmHg. The foot was secured in a rigid foot holder with elastic bandages, ensuring the medial and lateral malleoli were not compressed. Robotic system positioning and tracker placement were then confirmed, completing surgical preparation. Following final verification of patient information, a midline skin incision was made, and dissection was carried through subcutaneous tissue to the joint capsule. A medial parapatellar arthrotomy was performed, the patella was everted laterally, and the knee was flexed to expose the joint. Hypertrophic synovium was excised, and the remaining meniscus and cruciate ligaments were resected.

Periarticular osteophytes were intentionally preserved at this stage to avoid compromising subsequent bone registration accuracy. Concurrently, the assistant inserted two parallel Schanz pins into the tibia and femur using a drill guide. The tibial pin was placed ≥ 8 cm distal to the tibial tuberosity to avoid interfering with tibial osteotomy. The femoral pin was positioned approximately 8 cm proximal to the knee joint. Reference arrays were mounted on the pins, positioned approximately 4 cm above the skin surface, and adjusted to ensure rigid fixation and optimal optical tracking. Rigid fixation of the reference arrays was confirmed (Fig. 2A). Following the system's prompts, verification of the blunt and pointed probes was performed sequentially. The limb was rotated to determine the femoral head center, and the medial and lateral malleoli were marked using the blunt probe. Guided by the operative interface, the pointed probe was used to complete femoral and tibial surface registration (Fig. 2B). Upon completion, the robotic arm automatically positioned the cutting guide over the osteotomy site. The system performed final adjustments, confirmed positioning on the display, and locked the arm. The surgeon then performed osteotomies using an oscillating saw in the following sequence: distal femur, anterior condyle, posterior chamfer, anterior chamfer, and tibial plateau (Fig. 2C). The remaining meniscus was resected. Trial components were inserted to assess flexion-extension gap balance, lower extremity alignment in extension, and patellar tracking (Fig. 2D). Once satisfactory, the trial components were removed, the operative site was irrigated with pulse lavage, and the definitive prosthesis was cemented into place. Following prosthesis implantation, the operative site was again irrigated with pulse lavage. The foot holder and tracker pins were removed. A periarticular multimodal analgesic cocktail was injected, and the wound was closed in layers. A compressive sterile dressing was applied.

CO-TKA group:

TKA was performed using conventional instrumentation and technique. Following satisfactory anesthesia, the patient was positioned supine, and a pneumatic tourniquet was applied at the proximal thigh, identical to the RA-TKA protocol. After sterile preparation and draping, the limb was elevated and exsanguinated with an Esmarch bandage. The tourniquet was inflated to 300 mmHg. The surgeon performed a midline approach and executed osteotomies using conventional cutting guides and intramedullary alignment rods. Osteotomy depth and angle were fine-tuned intraoperatively based on anatomical landmarks and gap assessment. Following osteotomy, trial components were inserted to assess flexion-extension gap balance and lower extremity alignment. If unsatisfactory, adjustments were made and reassessed until optimal balance and alignment were achieved. The definitive prosthesis was implanted, the operative site was irrigated with pulse lavage, and the wound was closed in layers. A compressive sterile dressing was applied.

Postoperative Management:

No surgical drains were placed. All patients received identical oral nonsteroidal anti-inflammatory drugs for analgesia on postoperative day 1. On postoperative day 2, patients were encouraged to ambulate with a walker, which was continued for 3–6 weeks and discontinued based on individual rehabilitation

progress. Low-molecular-weight heparin calcium was administered for thromboprophylaxis starting on postoperative day 2 for 14 consecutive days.

3. Outcome Measures

3.1 Intraoperative Parameters

- a. Operative time: Defined as the interval from skin incision to skin closure.
- b. Intraoperative bleeding: After the operation, the intraoperative bleeding of the patient was counted.
- c. Perioperative hemoglobin change: Preoperative and postoperative day 1 hemoglobin levels were measured to estimate occult blood loss using the Gross formula.
- d. Incision length: Measured with a ruler and recorded in centimeters.
- e. Soft tissue injury severity: Post-TKA knee stability is primarily maintained by the medial collateral ligament (MCL), lateral collateral ligament (LCL), popliteal tendon, and iliotibial band. Iatrogenic soft tissue injury was graded using the modified Hampp classification^[14] (Table 1). Assessment was performed intraoperatively by the attending surgeon immediately following prosthesis implantation and prior to wound closure, based on direct visual inspection and palpation of each structure

Table 1
Types of soft tissue injuries

Damage level	I	II	III	IV
Scope of damage	≤ 5%	6–25%	26–75%	≥ 76%

3.2 Radiographic Outcomes

- Postoperative anteroposterior and lateral knee radiographs, as well as full-length lower extremity radiographs, were obtained (Fig. 3). The following parameters were measured:
- Hip-knee-ankle angle (HKA): The femoral mechanical axis was defined as the line connecting the center of the femoral head and the center of the knee. The tibial mechanical axis was defined as the line connecting the center of the knee and the center of the ankle. The HKA was measured as the angle between these two axes.
- Mechanical lateral distal femoral angle (mLDFA): The angle between the distal femoral joint line tangent and the femoral mechanical axis.

Mechanical medial proximal tibial angle (mMPTA): The angle between the proximal tibial joint line tangent and the tibial mechanical axis.

Sagittal tibial component angle (sTCA): The posterior angle between the tibial component base plate and the tibial anatomical axis.

Sagittal femoral component angle (sFCA): The posterior angle between the femoral component and the distal femoral anatomical axis.

Restoration of HKA within 0°- 3° of neutral on coronal radiographs is associated with reduced polyethylene wear and lower revision rates^[15]. Deviations beyond this range increase the risk of prosthetic loosening and poor functional outcomes. Therefore, the lower extremity alignment correction (LEAC) rate was defined as the proportion of patients achieving postoperative HKA within 3° of neutral.

3.3 Postoperative indicators

a. Functional scores: Patients were evaluated at 3 and 6 months postoperatively using the Oxford Knee Score (OKS), Knee Society Score (KSS), and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).

b. Postoperative pain: Knee pain was assessed daily during the first postoperative week using a visual analog scale (VAS).

c. Knee range of motion (ROM): Active knee flexion was measured daily from postoperative day 2 through day 7 using a standard goniometer.

3.4 Postoperative complications

Postoperative adverse events, including periprosthetic joint infection, deep vein thrombosis, prosthetic loosening, and revision surgery, as well as robotic-specific complications (e.g., soft tissue injury, guide pin fracture, pin tract infection), were documented throughout the follow-up period.

4. Statistical Analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean $\pm$ standard deviation (SD). Between-group comparisons of continuous variables were performed using independent t-tests for normally distributed data and Mann-Whitney U tests for non-normally distributed data. Categorical variables were analyzed using chi-square tests. Repeated-measures analysis of variance (ANOVA) was used to compare longitudinal outcomes (VAS pain scores and active knee ROM during the first postoperative week) between groups. A two-sided P-value < 0.05 was considered statistically significant.

Results

1. Patient Characteristics

A total of 161 patients met the inclusion criteria and underwent primary unilateral TKA: 76 in the RA-TKA group and 85 in the CO-TKA group. All patients were treatment-naïve with no prior knee surgery. Demographic and baseline clinical characteristics were comparable between groups (Table 2).

Table 2
Characteristics of patients

Age(year)	RA-TKA	CO-TKA	P
	65.8 ± 8.8	68.6 ± 9.6	>0.05
Gender(Male / Female)	30/46	35/50	>0.05
BMI (kg/m ²)	26.8 ± 4.4	25.6 ± 3.9	>0.05
Preoperative KSS-F score	46.6 ± 8.2	50.1 ± 9.8	>0.05
Preoperative KSS-K	58.6 ± 7.4	55.6 ± 8.0	>0.05
Preoperative WOMAC score	78.2 ± 5.6	80.1 ± 7.6	>0.05
Preoperative OKS score	45.2 ± 8.8	43.8 ± 9.5	>0.05
Preoperative VAS score	4.2 ± 2.3	4.6 ± 2.8	>0.05
Preoperative knee mobility	93.2 ± 5.2	90.9 ± 4.8	>0.05
Abbreviations: BMI, body mass index; CO-TKA, conventional total knee arthroplasties; RA-TKA, robot-assisted total knee arthroplasty; KSS, knee society score; P: P-value; WOMAC, western Ontario McMaster university osteoarthritis index.			

2. Intraoperative Outcomes

No significant difference was observed in operative time between the RA-TKA and CO-TKA groups (72.5 ± 25.1 vs. 75.6 ± 18.9 minutes, $P = 0.30$). However, RA-TKA was associated with reduced intraoperative blood loss (229.0 ± 65.7 vs. 246.9 ± 65.6 mL, $P = 0.09$) and significantly smaller perioperative hemoglobin decline (10.2 ± 6.8 vs. 15.5 ± 10.3 g/L, $P < 0.001$). Incision length was significantly longer in the RA-TKA group (12.1 ± 1.2 vs. 10.2 ± 3.8 cm, $P < 0.001$) (Table 3).

Table 3
Intraoperative indicators

RA-TKA	Surgical time	Intraoperative bleeding	Hemoglobin changes	Surgical incision length
	72.5 ± 25.1	229.0 ± 65.7	10.2 ± 6.8	12.1 ± 1.2
CO-TKA	75.6 ± 18.9	246.9 ± 65.6	15.5 ± 10.3	10.2 ± 3.8
<i>P</i>	<i>P</i> = 0.30	<i>P</i> = 0.09	<i>P</i> < 0.001	<i>P</i> < 0.001
Abbreviations: CO-TKA, conventional total knee arthroplasties; RA-TKA, robot-assisted total knee arthroplasty; <i>P</i> : <i>P</i> -value				

3. Soft Tissue Injury

Iatrogenic soft tissue injury was graded using the modified Hampp classification^[14]. RA-TKA was associated with significantly less severe soft tissue injury compared with CO-TKA (Table 4).

Table 4
Damage to soft tissues

Damage level		0	I	II	III	IV
MCL	RA-TKA	24	40	10	2	0
	CO-TKA	10	50	18	6	1
	P_1	0.013				
LCL	RA-TKA	66	8	2	0	0
	CO-TKA	70	12	3	0	0
	P_2	0.735				
Popliteal tendon	RA-TKA	65	9	2	0	0
	CO-TKA	52	24	8	1	0
	P_3	0.003				
Abbreviations: CO-TKA, conventional total knee arthroplasties; RA-TKA, robot-assisted total knee arthroplasty; MCL:medial collateral ligament; LCL:lateral collateral ligament; P_1 :MCL damage in both groups; P_2 :Two groups of LCL injury; P_3 :popliteal tendon damage in both groups.						

MCL: The RA-TKA group demonstrated a lower incidence of severe injury, with 24 patients (31.6%) showing no injury, 40 (52.6%) Grade I, 10 (13.2%) Grade II, and 2 (2.6%) Grade III. In contrast, the CO-TKA group had 10 patients (11.8%) with no injury, 50 (58.8%) Grade I, 18 (21.2%) Grade II, 6 (7.1%) Grade III, and 1 (1.2%) Grade IV (*P* = 0.013).

LCL: No significant between-group difference was observed in LCL injury severity ($P = 0.735$). In the RA-TKA group, 66 patients (86.8%) had no injury, 8 (10.5%) had Grade I, and 2 (2.6%) had Grade II injury. The corresponding figures in the CO-TKA group were 70 (82.4%), 12 (14.1%), and 3 (3.5%).

Popliteal tendon: Robotic assistance significantly reduced popliteal tendon injury ($P = 0.003$). The RA-TKA group had 65 patients (85.5%) with no injury, 9 (11.8%) with Grade I, and 2 (2.6%) with Grade II. The CO-TKA group had 52 (61.2%) with no injury, 24 (28.2%) with Grade I, 8 (9.4%) with Grade II, and 1 (1.2%) with Grade III.

4. Radiographic Outcomes

Postoperative full-length lower extremity radiographs were obtained in all patients. The RA-TKA group demonstrated significantly more accurate component positioning: HKA ($1.2 \pm 1.1^\circ$ vs. $1.7 \pm 1.8^\circ$, $P = 0.027$), mLDFA ($1.5 \pm 1.2^\circ$ vs. $2.1 \pm 1.5^\circ$, $P = 0.015$), mMPTA ($1.3 \pm 0.9^\circ$ vs. $1.9 \pm 1.5^\circ$, $P = 0.046$), sTCA ($1.2 \pm 2.5^\circ$ vs. $1.6 \pm 2.8^\circ$, $P = 0.026$), and sFCA ($1.0 \pm 1.2^\circ$ vs. $1.6 \pm 1.8^\circ$, $P = 0.028$) (Table 5).

Table 5
Postoperative imaging results

RA-TKA	HKA	mLDFA	mMPTA	sTCA	sFCA	LEAC
	1.2 ± 1.1	1.5 ± 1.2	1.3 ± 0.9	1.2 ± 2.5	1.0 ± 1.2	74/76
CO-TKA	1.7 ± 1.8	2.1 ± 1.5	1.9 ± 1.5	1.6 ± 2.8	1.6 ± 1.8	79/85
P	0.027	0.015	0.046	0.026	0.028	0.35
Abbreviations: CO-TKA, conventional total knee arthroplasties; RA-TKA, robot-assisted total knee arthroplasty; HKA: hipe knee ankle angle; LDFA: lateral distal femoral angle; MPTA: medial proximal tibial angle; P:P-value sTCA: sagittal tibial component angle; sFCA: sagittal femur component angle. LEAC: lower extremity alignment correction; P: P-value						

The lower extremity alignment correction (LEAC) rate (HKA within 3°of neutral) was 97.4% (74/76) in the RA-TKA group and 92.9% (79/85) in the CO-TKA group, with no significant between-group difference ($P = 0.35$). Two RA-TKA patients (2.6%) and six CO-TKA patients (7.1%) failed to achieve correction within 3°, all due to severe preoperative deformity.

5. Functional Outcomes

5.1 Three-month outcomes

No significant between-group differences were observed in any functional score at 3 months postoperatively (Table 6): KSS-K (85.4 ± 4.6 vs. 86.3 ± 5.2 , $P = 0.26$), KSS-F (84.4 ± 3.9 vs. 88.1 ± 2.2 , $P = 0.07$), WOMAC (24.5 ± 8.2 vs. 23.8 ± 6.8 , $P = 0.24$), and OKS (27.5 ± 6.2 vs. 26.8 ± 8.9 , $P = 0.33$).

5.2 Six-month outcomes

At 6 months, the RA-TKA group demonstrated a significantly higher KSS-K score (95.2 ± 8.6 vs. 89.8 ± 9.3 , $P = 0.03$). No significant differences were observed in KSS-F (87.5 ± 6.9 vs. 85.1 ± 5.2 , $P = 0.12$), WOMAC (18.6 ± 9.0 vs. 18.8 ± 8.2 , $P = 0.33$), or OKS (19.6 ± 8.3 vs. 20.6 ± 9.8 , $P = 0.22$) (Table 6).

Table 6 Joint scores after surgery			
3 months after surgery	RA-TKA	CO-TKA	<i>P</i>
KSS-K score	85.4 ± 4.6	86.3 ± 5.2	0.26
KSS-F score	84.4 ± 3.9	88.1 ± 2.2	0.07
WOMAC score	24.5 ± 8.2	23.8 ± 6.8	0.24
OKS score	27.5 ± 6.2	26.8 ± 8.9	0.33
6 months after surgery			
KSS-K score	95.2 ± 8.6	89.8 ± 9.3	0.03
KSS-F score	87.5 ± 6.9	85.1 ± 5.2	0.12
WOMAC score	18.6 ± 9.0	18.8 ± 8.2	0.33
OKS score	19.6 ± 8.3	20.6 ± 9.8	0.22
Abbreviations: CO-TKA, conventional total knee arthroplasties; RA-TKA, robot-assisted total knee arthroplasty; <i>P</i> : <i>P</i> -value			

5.3 Early postoperative pain and range of motion

Daily VAS pain scores and active knee ROM during the first postoperative week are presented in Table 7. Repeated-measures ANOVA results are shown in Table 8.

Table 7
Postoperative knee mobility and VAS pain scores

	Postoperative VAS score			Postoperative active mobility of the knee		
	RA-TKA	CO-TKA	<i>P</i>	RA-TKA	CO-TKA	<i>P</i>
Day 1	7.6 ± 0.7	8.4 ± 0.5	<0.001	16.8 ± 4.1	17.3 ± 4.9	0.58
Day 2	6.7 ± 0.7	7.7 ± 0.7	<0.001	33.1 ± 6.9	29.8 ± 8.4	0.56
Day 3	5.8 ± 0.7	6.8 ± 0.8	<0.001	68.7 ± 14.5	61.6 ± 12.3	<0.001
Day 4	5.5 ± 0.6	5.9 ± 0.9	0.02	76.1 ± 10.3	71.9 ± 11.0	0.01
Day 5	4.6 ± 0.7	4.9 ± 0.9	0.01	82.4 ± 9.8	77.5 ± 10.5	0.02
Day 6	3.0 ± 0.8	3.9 ± 0.8	<0.001	88.6 ± 8.9	83.2 ± 9.6	0.03
Day 7	2.3 ± 0.5	3.3 ± 0.5	0.10	104.5 ± 9.9	96.6 ± 7.7	<0.001
Abbreviations: CO-TKA, conventional total knee arthroplasties; RA-TKA, robot-assisted total knee arthroplasty; <i>P</i> : <i>P</i> -value						

Table 8
Postoperative Knee Mobility and Postoperative VAS Score Two-Way Repeated Measures ANOVA Measurements

	Between-subjects effects (group)		Within-subjects effects (time)		Group and Time Interaction	
	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
Postoperative VAS score	239.95	<0.001	1297.75	<0.001	7.11	<0.001
Postoperative active mobility of the knee	28.39	<0.001	2013.58	<0.001	5.27	<0.001
Abbreviations: CO-TKA, conventional total knee arthroplasties; RA-TKA, robot-assisted total knee arthroplasty; <i>P</i> : <i>P</i> -value						

Pain scores

Between-subjects effects demonstrated significantly lower VAS scores in the RA-TKA group compared with CO-TKA during the first postoperative week ($P < 0.001$). Within-subjects effects showed significant pain improvement over time in both groups ($P < 0.001$). A significant group $\times$ time interaction ($P < 0.001$) indicated that pain reduction trajectories differed between surgical approaches. Simple effects analysis revealed that RA-TKA patients reported lower pain scores from postoperative day 1 through day 6 ($P < 0.05$); however, the difference on day 7 did not reach statistical significance.(Table 7)

Knee ROM

Between-subjects effects showed significantly greater active knee ROM in the RA-TKA group compared with CO-TKA during the first postoperative week ($P < 0.001$). Within-subjects effects demonstrated gradual ROM improvement over time in both groups ($P < 0.001$). A significant group and time interaction ($P < 0.001$) indicated differential ROM recovery patterns between groups. Simple effects analysis confirmed superior ROM recovery in the RA-TKA group at all time points from postoperative day 2 through day 7 (Table 7).

6. Complications

During the 6-month follow-up period, complications were limited to lower extremity deep vein thrombosis (DVT) in 1 RA-TKA patient (1.3%) and 2 CO-TKA patients (2.4%). Two RA-TKA patients (2.6%) experienced transient postoperative femoral pain attributed to tracker pin placement; no pin tract infections occurred. No prosthetic joint infections, aseptic loosening, or revision surgeries were observed in either group.

Discussion

Knee osteoarthritis (KOA) is a leading cause of chronic knee pain and disability in older adults, significantly impairing quality of life. Its incidence continues to rise as global populations age^[16]. Total knee arthroplasty is a well-established, highly effective intervention widely regarded—alongside total hip arthroplasty—as one of the most successful surgical procedures of the 20th century. By resurfacing damaged articular cartilage with prosthetic components, TKA reliably alleviates pain, restores mobility, and improves quality of life in patients with end-stage KOA^[17]. Although TKA is increasingly performed worldwide, conventional techniques remain limited by the difficulty of achieving optimal lower extremity alignment through accurate bone resection, which can compromise patient satisfaction and prosthesis longevity^[18, 19]. CO-TKA depends on manual instrumentation for intraoperative knee parameter assessment and prosthesis selection. Despite advances in implant design and instrumentation, CO-TKA has a substantial learning curve and remains heavily dependent on subjective intraoperative judgment, resulting in variable outcomes. Moreover, published evidence indicates that even in the hands of experienced surgeons, patient satisfaction following CO-TKA plateaus at approximately 80%, with nearly 20% of patients remaining dissatisfied^[20, 21]. To address these limitations, RA-TKA has garnered increasing attention among joint surgeons, primarily because of its capacity for detailed preoperative planning and enhanced surgical precision. Although RA-TKA has demonstrated favorable outcomes in numerous studies, clinical data on the Hong-Hu system remain scarce. The present study was designed to evaluate the safety and efficacy of Hong-Hu RA-TKA relative to conventional techniques.

1. Intraoperative Outcomes

Operating time

Prolonged operative time has been cited as a barrier to RA-TKA adoption. Several studies have reported significantly longer operative times with robotic assistance^[22–24]. Operative time exceeding 120 minutes is associated with a 1.8-fold increased risk of surgical site infection, a catastrophic complication in TKA^[25, 26]. RA-TKA requires tracker placement and bone registration, contributing to longer operative times—a finding corroborated by multiple studies. Contrary to previous reports, the present study found no significant difference in operative time between groups. This may be attributed to workflow optimization: while the assistant placed trackers, the surgeon initiated joint exposure, enabling parallel rather than sequential workflow. Consequently, when bone registration was initiated, trackers were already in place, eliminating setup delays. During registration, the surgeon maintained continuous screen visualization while performing bimanual probe manipulation based on anatomical familiarity, rather than alternating attention between the screen and surgical field. This approach ensured efficient, successful registration on the first attempt. This strategy requires thorough familiarity with knee anatomy. Additionally, RA-TKA saves time by eliminating femoral intramedullary canal violation and minimizing intraoperative osteotomy adjustments. Kayani et al^[27] reported comparable findings: operative time decreased significantly after 7 RA-TKA cases. Subsequent studies have corroborated these findings. Kebin et al^[28] analyzed 140 RA-TKA and 60 CO-TKA cases, demonstrating that after 1 year of robotic experience, mean operative time was significantly shorter than with conventional techniques, particularly in complex cases. Chen et al.^[29] demonstrated a definite learning curve for RA-TKA; upon its completion, operative times were comparable to CO-TKA.

Intraoperative Blood Loss and Perioperative Hemoglobin Changes

Intraoperative blood loss correlates with incision length and operative duration. Increased blood loss elevates the risk of postoperative infection and may necessitate allogeneic transfusion, increasing both economic burden and transfusion-related complications. In the present study, overt blood loss was quantified intraoperatively. Because a pneumatic tourniquet was used, occult blood loss was estimated from perioperative hemoglobin changes using the Gross formula, enabling comprehensive assessment of total blood loss. Results demonstrated that RA-TKA significantly reduced both intraoperative overt and postoperative occult blood loss compared with CO-TKA. Kayani et al.^[17] reported comparable findings in a matched cohort of 40 RA-TKA and 40 CO-TKA patients, using perioperative hemoglobin changes to estimate total blood loss. This reduction may be attributed to several factors. First, RA-TKA eliminates femoral intramedullary canal violation, reducing medullary trauma and associated blood loss. Second, precise preoperative planning and robotic guidance enable accurate osteotomy, minimizing soft tissue trauma and vascular injury—particularly to the periosteal capillary network. Combined with comparable operative times, these factors contribute to reduced total blood loss, predominantly occult loss.

Soft Tissue Injury

Soft tissue injury severity is an important outcome measure in TKA. This study graded MCL, LCL, and popliteal tendon injury using the modified Hampp classification and measured incision length to comprehensively assess soft tissue trauma. RA-TKA significantly reduced soft tissue injury but required longer incisions. The increased incision length in the RA-TKA group was necessitated by lower limb immobilization in a foot holder, which required complete wound exposure. Notably, for complex cases, RA-TKA did not require longer incisions than CO-TKA, suggesting that the robotic setup may be particularly advantageous in challenging anatomical scenarios. Regarding other soft tissue injuries, preoperative planning in RA-TKA enables direct intraoperative execution of the planned osteotomy, minimizing the need for extensive soft tissue release. Following exposure, the robotic arm is positioned according to intraoperative findings. Once positioned, the arm locks automatically, allowing the surgeon to perform osteotomy with an oscillating saw. Intraoperative dynamic referencing enables real-time assessment of knee stability, alignment, and ROM. If osteotomy is suboptimal, adjustments are made via the robotic interface, and the arm automatically repositions. The surgeon then readjusts and performs osteotomy without repeated soft tissue release, thereby minimizing soft tissue trauma. Khlopas et al. [30] compared soft tissue injuries in 6 RA-TKA and 7 CO-TKA cases, reporting PCL injuries in 2 CO-TKA patients but none in the RA-TKA group, along with more extensive soft tissue trauma in the CO-TKA cohort. Minimizing intraoperative soft tissue injury reduces postoperative knee swelling and pain, improves early mobility, and accelerates functional recovery. In a subsequent study by the same group, RA-TKA was associated with reduced postoperative pain, improved early functional recovery, and shorter hospital stay compared with CO-TKA^[17].

2. Osteotomy Accuracy

Accurate component positioning and bone resection are critical to preventing postoperative prosthetic malalignment. This requires meticulous preoperative planning and precise intraoperative execution. Inaccurate osteotomy may result in component malpositioning, lower extremity malalignment, increased polyethylene wear, and higher revision rates^[31]. Studies have demonstrated that RA-TKA achieves more satisfactory lower extremity alignment^[32, 33]. Enhanced precision is the primary motivation for surgeons adopting robotic systems.

This study assessed osteotomy accuracy using postoperative HKA, mLDFA, mMPTA, sTCA, and sFCA, and calculated the lower extremity alignment correction (LEAC) rate. Results demonstrated that RA-TKA achieved significantly more accurate osteotomy and superior lower extremity alignment correction compared with CO-TKA. This aligns with expectations, as optimal alignment requires both meticulous preoperative planning and precise intraoperative execution. RA-TKA utilizes preoperative CT data to generate three-dimensional models, facilitating intuitive surgical planning with ample time for preoperative design and simulation of anticipated outcomes. Intraoperatively, RA-TKA provides highly accurate positioning (< 2 mm) and enables real-time monitoring of joint space after osteotomy, facilitating accurate assessment of lower extremity alignment. If initial osteotomy is suboptimal, intraoperative robotic fine-tuning can optimize outcomes. The capacity for intuitive preoperative design,

dynamic flexion-extension gap assessment, and intraoperative readjustment confers clear advantages in lower extremity alignment correction, particularly in patients with severe deformities. Marchand et al.^[34] reported that RA-TKA achieved neutral alignment in 100% of patients with severe varus deformity. Although Abdel et al. found no difference in polyethylene insert longevity between HKA > 3° and 0°–3° deviations, polyethylene wear is theoretically more uniform and implant longevity potentially greater within the 0°–3° range^[35].

3. Functional Outcomes

Early postoperative pain reduction and functional recovery optimization are foundational to patient satisfaction and long-term outcomes. However, few studies have specifically analyzed early postoperative recovery trajectories. This study assessed functional recovery by recording daily VAS pain scores and active knee ROM during the first postoperative week. Results demonstrated gradual improvement in pain scores and knee ROM in both groups during the first postoperative week. However, RA-TKA patients demonstrated superior pain resolution and ROM recovery. The accelerated pain resolution in the RA-TKA group may be attributed to several factors. First, femoral osteotomy without intramedullary canal violation reduces postoperative intra-articular bleeding and knee swelling. Second, the RA-TKA group received medial-pivot prostheses, which achieve stability through conforming articular geometry rather than a posterior stabilizing post, better replicating native knee kinematics and potentially improving patient-perceived outcomes.

The KSS comprises knee and function subscores, providing comprehensive functional assessment. The WOMAC focuses primarily on pain (24 items), limiting its scope, whereas the OKS is a TKA-specific scale emphasizing functional improvement and subjective patient perception. This study employed KSS, WOMAC, and OKS for comprehensive functional evaluation. Results showed comparable WOMAC, OKS, and KSS functional scores between groups at 3 months, with the RA-TKA group demonstrating a significantly higher KSS-K score at 6 months. Patient satisfaction is influenced by multiple factors, including ligament balance, flexion-extension gaps, and prosthesis alignment, all of which are critical for post-TKA function and implant durability^[36]. The RA-TKA group's more accurate component positioning and reduced soft tissue trauma likely contributed to higher satisfaction. Recent studies have reported comparable findings. Marchand et al.^[37] demonstrated superior 1-year functional recovery with RA-TKA. Smith et al.^[36] reported higher postoperative satisfaction with RA-TKA, with significant KSS functional score improvements at 6 weeks ($P = 0.02$) and 1 year ($P = 0.005$), as well as significant KSS knee score improvement at 1 year. Arthur et al.^[38] reported excellent patient-reported outcome measure (PROM) results and fewer early complications at 2 years. However, conflicting evidence exists. In a 10-year study of 1,539 patients, Kim et al.^[39] found no significant between-group difference in knee scores. Li et al.^[20] followed 73 RA-TKA and 77 CO-TKA patients, reporting significant improvement in both groups but no significant between-group difference. This discrepancy may be attributed to several factors. CO-TKA outcomes are highly surgeon-dependent; experienced operators can achieve excellent results, potentially

minimizing between-group differences. Additionally, robotic technology has evolved substantially. The robotic system in Kim et al.'s study^[39] was an earlier-generation platform, which may have had technical limitations affecting outcomes. Recent studies with shorter follow-up have reported superior outcomes, likely attributable to more advanced robotic systems. Short-term functional outcomes are primarily influenced by soft tissue status and prosthesis fit, whereas long-term outcomes depend on lower extremity alignment. Li et al.'s 3-month follow-up without soft tissue assessment may have precluded detection of between-group differences. Longer follow-up is required to determine whether RA-TKA provides superior long-term functional recovery.

4. Postoperative Complications

At minimum 6-month follow-up, no significant between-group difference in complication rates was observed. Neither group experienced guide pin fractures or pin tract infections. These findings are consistent with those of Kim et al.^[39] and Song et al.^[40] Park and Lee^[32] studied the RA-TKA learning curve, reporting higher early complication rates—including superficial infection, patellar tendon rupture, patellar dislocation, supracondylar fracture, patellar fracture, and peroneal nerve injury—which decreased significantly after completion of the learning curve (30 cases), with no subsequent between-group difference in complications. Naziri et al.^[41] similarly reported no significant between-group difference in complications at 30, 60, and 90 days. We speculate that the attending surgeon's extensive CO-TKA experience, combined with preoperative robotic training and simulation drills, mitigated learning curve effects. The surgeon's proficiency in conventional techniques minimized the need for intraoperative adjustments, facilitating rapid adaptation to the robotic workflow.

limitations

First, this study evaluated only the Hong-Hu robot, without comparison to other robotic platforms; Second, functional score assessment was performed by a single assessor without standardized training, potentially introducing measurement bias; Third, both groups were operated by a single experienced surgeon. While this minimized learning curve effects, it may have minimized between-group differences due to the surgeon's high baseline proficiency with conventional techniques, limiting the generalizability of findings to less experienced surgeons. Future studies should include surgeons with varying experience levels to comprehensively evaluate RA-TKA. Fourth, patient allocation was non-randomized based on patient preference after informed consent, introducing potential selection bias. Patients choosing robotic assistance may have differed in baseline characteristics not captured in this study, such as socioeconomic status or baseline pain expectations. Fifth, the 6-month follow-up period is relatively short, necessitating longer-term evaluation.

Conclusion

Compared with CO-TKA, Hong-Hu RA-TKA was associated with reduced intraoperative blood loss and soft tissue injury, more accurate tibial osteotomy and prosthesis positioning, and improved early postoperative pain control and knee ROM. No significant differences were observed in mid-term functional scores at 3 months. At 6 months, the RA-TKA group demonstrated a significantly higher KSS-K score.

Therefore, Hong-Hu RA-TKA demonstrates superior early postoperative outcomes compared with CO-TKA. Longer follow-up is required to determine its long-term efficacy.

Declarations

Ethics approval and consent to participate

This retrospective cohort study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Gansu Provincial People's Hospital, Lanzhou, China (Approval No. 2023 – 294). Written informed consent to participate was obtained from all participants.

Consent for publication

Written informed consent for publication of the participants' clinical details and the images presented in Fig. 2 was obtained from all participants concerned.

Competing interests

All authors declare that there are no conflicts of interest.

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Author Contribution

Hong-zhang Guo conceived and designed the study. Hui Wang and Qing-hao Cheng acquired the data. Jin-sheng Wang and De-zheng Li analyzed and interpreted the data. Hui Wang drafted the manuscript. Hong-zhang Guo critically revised the manuscript. All authors read and approved the final manuscript.

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Not applicable.

Data Availability

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

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Figures

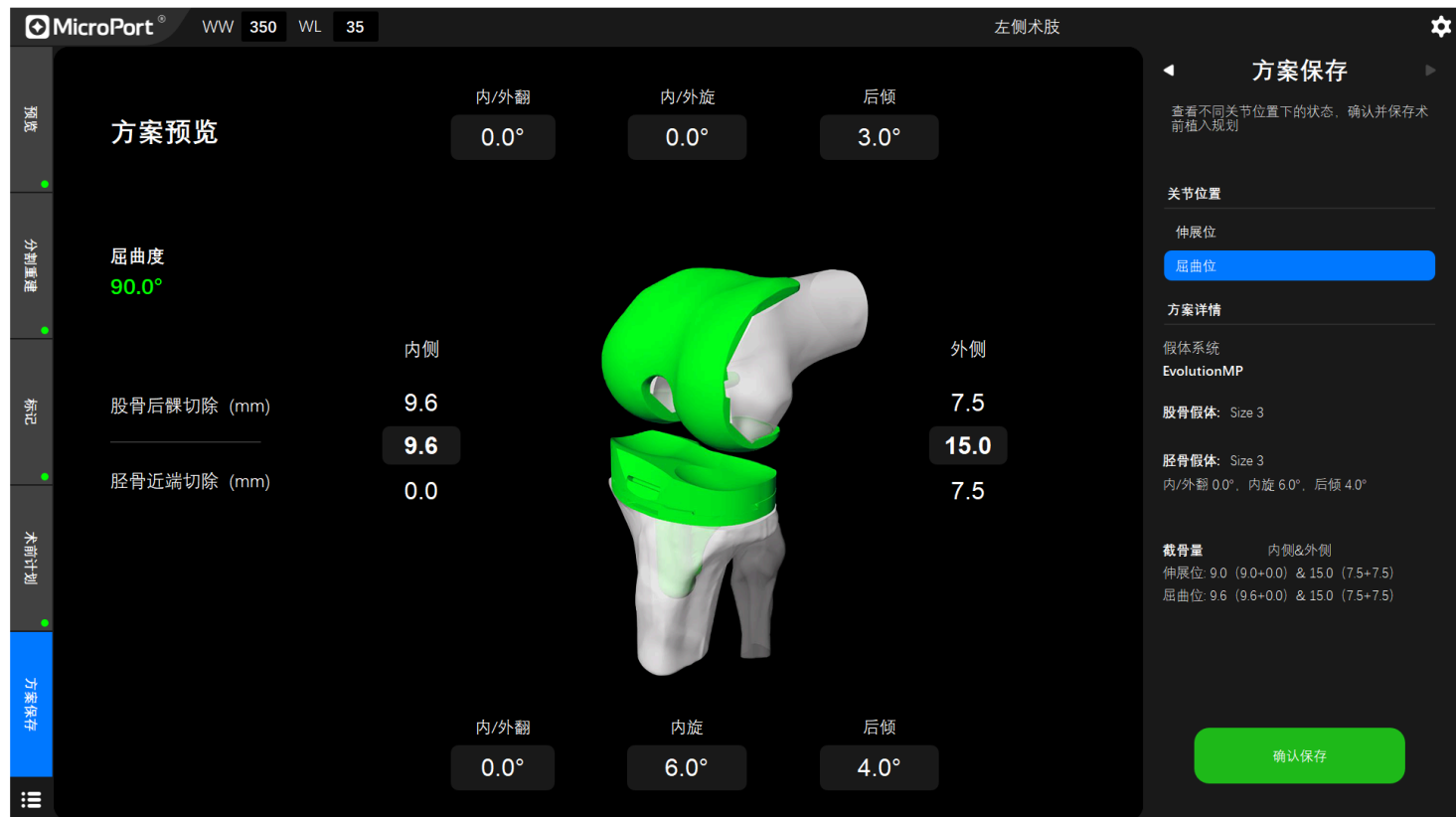


Figure 1

Pre-surgical joint reconstruction and osteotomy planning based on patient computed tomography (CT) data using the Hong-hu robotic system.

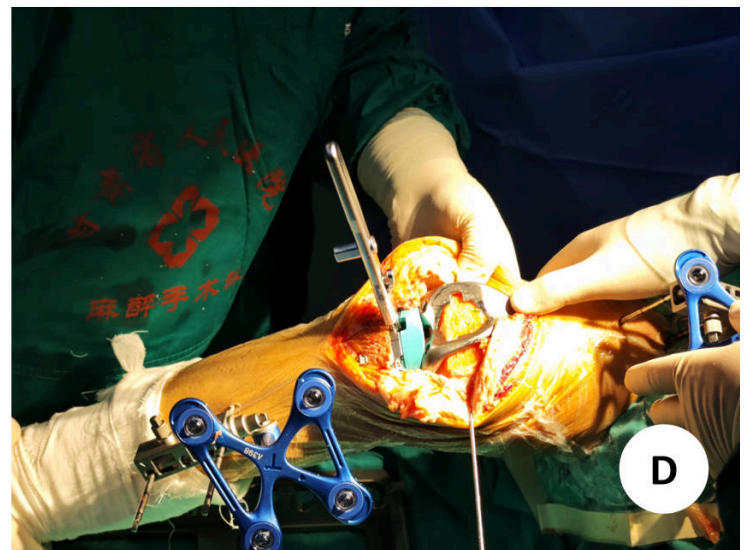


Figure 2

Intraoperative procedures during robotic-assisted total knee arthroplasty (RA-TKA). (A) Insertion of tracking pins in the femur and tibia. (B) Registration of knee anatomical landmarks using target probes. (C) Execution of precise bone resections using an oscillating saw guided by the robotic system. (D) Evaluation of the lower extremity mechanical axis and gap balancing after trial component insertion.

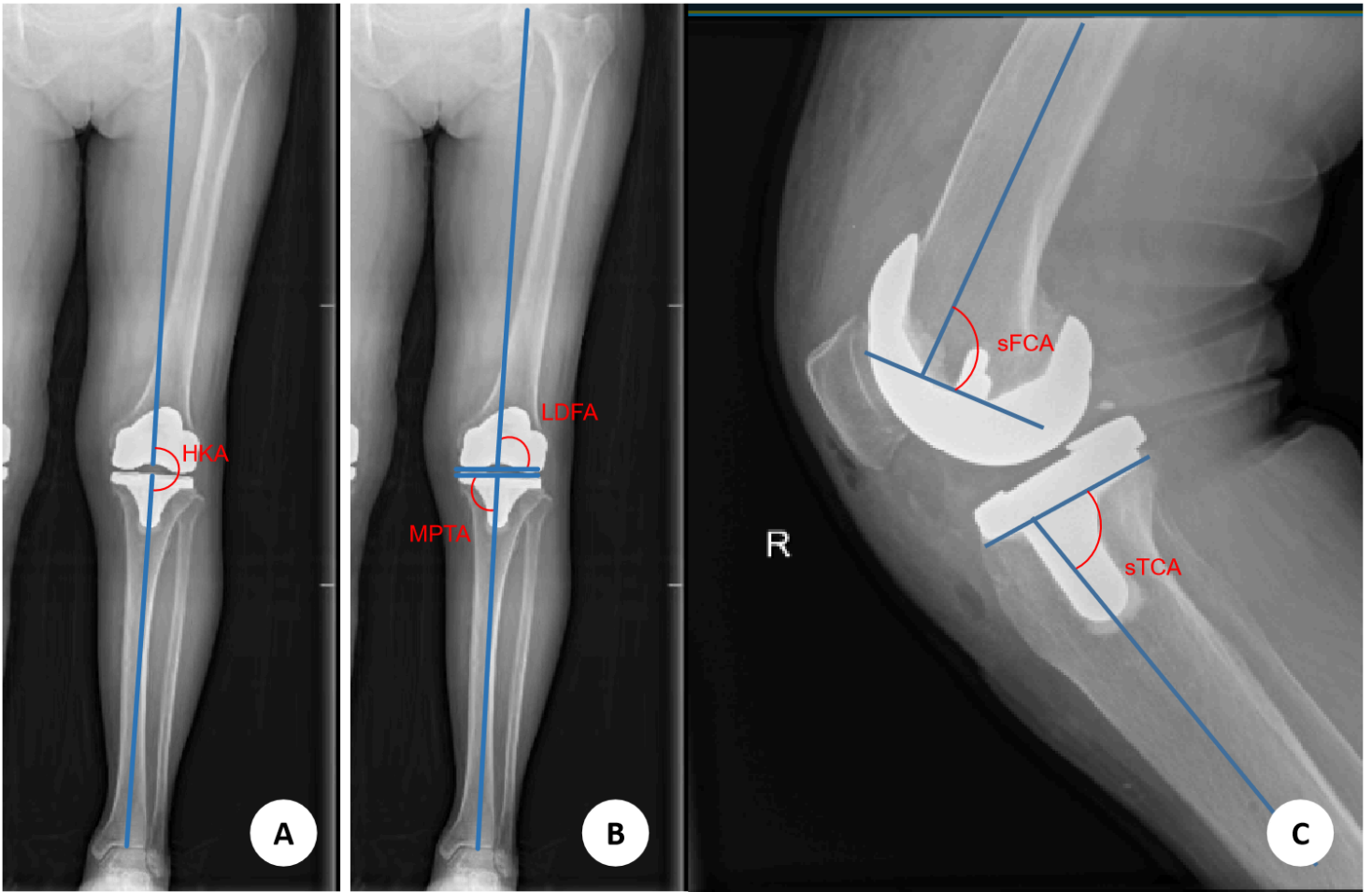


Figure 3

Postoperative radiographic evaluation. Measurement of (A) hip-knee-ankle angle (HKA), (B) mechanical lateral distal femoral angle (mLDFA) and mechanical medial proximal tibial angle (mMPTA), and (C) sagittal femoral component angle (sFCA) and sagittal tibial component angle (sTCA).