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ORIGINAL ARTICLE

Effect of posterior-stabilized and cruciate-retaining implants on three-dimensional kinematic characteristics after total knee arthroplasty

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Total knee arthroplasty (TKA) has become a widely accepted surgical intervention for patients with advanced knee osteoarthritis (OA), significantly enhancing pain relief and functional outcomes.[1-6] Currently, there are primarily two implant designs, posterior-stabilized (PS) and cruciate-retaining (CR) implants, which achieve satisfactory clinical outcomes. The choice of implants remains a focal point of academic debate.[7,8] The PS implants provide enhanced stability and support by incorporating

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ABSTRACT

Objectives: This study aimed to analyze the effects of posterior-stabilized (PS) and cruciate-retaining (CR) total knee arthroplasty (TKA) on early postoperative three-dimensional (3D) dynamic and kinematic characteristics in patients with unilateral knee osteoarthritis (OA).

Patients and methods: A retrospective analysis of prospectively collected data from 90 patients with unilateral TKA between February 2021 and September 2021 was conducted using a 3D kinematic analysis system before and six months after TKA. This patient group included 57 patients (10 males, 47 females; mean age: 69.5±7.5 years; range, 53 to 85 years) who underwent PS TKA and 33 patients (11 males, 22 females; mean age: 67.9±8.8 years; range, 45 to 86 years) who underwent CR TKA. The kinematic characteristics and clinical results of the two groups were compared. Clinical evaluation included the Hospital for Special Surgery knee score and range of motion (ROM). Twenty-eight healthy controls (9 males, 19 females; mean age: 64.5±2.9 years; range, 61 to 75 years) without knee OA matched for age, weight, height, and body mass index were recruited. The kinematic characteristics of the healthy control group were also evaluated.

Results: The PS group exhibited significant changes in basic gait parameters after TKA, including cadence ($p=0.046$), stride time ($p=0.011$), opposite foot off ($p<0.001$), opposite foot contact ($p=0.038$), step time ($p=0.005$), double support period ($p<0.001$), and foot off ($p=0.004$). No significant differences were observed in the kinematic parameters before and after TKA between the PS and CR groups, such as knee angle, moment, and force. The dynamic ROM of the CR group was greater than that of the PS group ($p<0.001$). Both the PS and CR groups showed significant deficiencies in flexion and extension function, including knee flexion moment, extension force, maximum flexion angle, and dynamic ROM, compared to healthy individuals. Throughout the gait cycle, both the PS and CR groups showed better knee joint stability compared to healthy individuals.

Conclusion: At six months postoperatively, both the PS and CR groups' gait patterns did not recover to a healthy state, and the CR group's gait pattern was more similar to OA. Compared to PS TKA, CR TKA allowed for greater dynamic ROM during gait. Despite exhibiting superior knee stability during gait, both implants' knee kinematics function remained inferior compared to healthy individuals.

Keywords: Arthroplasty, gait analysis, knee joint, knee prosthesis, osteoarthritis.

a post stabilized at the back of the joint space to emulate the function of the body's natural ligaments.[9] These implants require the removal of the anterior cruciate ligament and the posterior cruciate ligament (PCL), which is thought to affect the postoperative gait of the knee, resulting in poor subjective perception of the patient. Cruciate-retaining implants aim to simulate the kinematic characteristics of normal knee joints by preserving the PCL.[10] Bicruciate-retaining and bicruciate-substituting implants have also emerged, designed to restore normal kinematics by preserving the function of both cruciate ligaments. Studies on biomechanics, proprioception, and stability after TKA with different implant designs have yielded inconsistent results without definitive conclusions.[11] The distinct designs of these implants contribute to varying kinematic characteristics, which in turn influence clinical outcomes and patient satisfaction.[12,13] Comparative studies on the kinematic characteristics of PS TKA and CR TKA have relied on knee specimens or static three-dimensional (3D) images, lacking dynamic evaluation during movement.[14,15] Notably, since kinematic characteristics are inherently dynamic, static assessments often fail to capture these dynamics. Thus, the Vicon 3D system was used in this study.

The Vicon 3D kinematic analysis system, a high-precision motion capture technology, is extensively utilized in motion biomechanics research.[16] For patients who received TKA, this system provides precise, objective data that assists both physicians and patients in assessing improvements in postoperative kinematic function, joint stability, and rehabilitative progress.[17,18] This system has been employed to examine the postoperative kinematic functions of PS and CR implants, enabling a comprehensive and objective analysis of patient kinematic parameters, which include the gait cycle, stride length, gait symmetry, joint angles, and force distribution.[19,20]

The study aimed to assess the impact of PS and CR implants on kinematic characteristics and knee dynamic stability during gait and increase the understanding of the kinematics and contact mechanics of gait cycles following TKA with different implant designs, providing comprehensive insights into normal knee joint function. This study hypothesized that different implant designs in knee kinematics would exhibit different gait characteristics and that both PS and CR TKA gait patterns would not recover to a healthy state.

PATIENTS AND METHODS

A retrospective analysis of prospectively collected data was conducted in patients with knee OA who received TKA at the The First Affiliated Hospital, Sun Yat-sen University between February 2021 and September 2021. Participants were included if they met the following criteria: *(i)* diagnosed with knee OA and scheduled for unilateral TKA; *(ii)* deemed suitable for both PS and CR implants by preoperative examination, including no laxity or contracture of PCL and no severe coronary deformity (>25°) or flexion contracture (>30°); *(iii)* capable of walking 10 m unassisted; *(iv)* assessed with a complete 3D kinematic analysis. Exclusion criteria were as follows: *(i)* history of knee operation surgery; *(ii)* surgical history involving the hip or ankle; *(iii)* absence of radiographs; *(iv)* postoperative loss to follow-up; *(v)* complications such as implant infection, fracture, or dislocation. The study enrolled 90 patients. Of these patients, 57 (10 males, 47 females; mean age: 69.5±7.5 years; range, 53 to 85 years) underwent PS TKA (the PS group), and 33 (11 males, 22 females; mean age: 67.9±8.8 years; range, 45 to 86 years) underwent CR TKA (the CR group). Twenty-eight healthy controls (9 males, 19 females; mean age: 64.5±2.9 years; range, 61 to 75 years) without knee OA matched for age, weight, height, and body mass index were recruited. This control group comprised individuals with no history of lower limb disease and no lower limb pain in the past year The study protocol was approved by the Independent Ethics Committee for Clinical Research and Animal Experiments of First Affiliated Hospital of Sun Yat-sen University (date: 18.02.2021, no: 2021-571) and was registered in the Chinese Clinical Trial Registry (ChiCTR2100051302). Written informed consent was obtained from all participants. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Perioperative management

All patients were diagnosed preoperatively with end-stage knee OA, and a single attending surgeon and three residents performed all surgeries using standardized techniques. The indications for the PS implants were broader, and our selected patients met the criteria for both PS and CR implants. These implants were randomly supplied by the operating room supply department, except in cases where patients made specific requests; such cases were excluded from the trial. All prostheses were from the Zimmer Biomet Vanguard series (Cemented Vanguard Complete Knee System; Zimmer Biomet Inc., Warsaw, IN, USA). Surgical approaches included anterior median knee incision, medial parapatellar approach, removing the anterior cruciate ligament and meniscus, setting the femoral valgus angle to 6°, intramedullary localizations for femoral osteotomy, and extramedullary localizations for tibial osteotomy. When performing PS TKA, we removed the PCL attachment point and performed intercondylar fossa osteotomy. When performing CR TKA, we used the bone island technique to preserve PCL attachment points. We used a combination of measuring osteotomy and gap balancing osteotomy to adjust the flexion-extension gap balance. After a satisfactory test, bone cement was applied, and the prosthesis was implanted. The patella was not replaced in any case.

All patients, irrespective of whether a PS or CR implant was used, underwent a standardized rehabilitation program. The drainage tube was removed within 48 h after TKA, and patients received both intravenous and oral analgesics and standardized anticoagulation therapy, and an immediate postoperative radiograph was taken (Figure 1). Early postoperative nursing included assisted ankle joint exercises on the day following surgery. Static quadriceps muscle contractions were initiated on the first day after TKA under nurse supervision, with gradual increases in contraction frequency. Patients also performed straight leg lifts, ankle pump exercises, and limb circling exercises 20 times per session (three sessions daily). On the third day after TKA, exercises were intensified to enhance muscle strength and joint range of motion (ROM).

Kinematic analysis

The patient was instructed by a specialized rehabilitation physician to complete 3D kinematic analysis before and six months after TKA. The healthy controls also completed the collection of 3D kinematic characteristics by the same method. The Vicon 3D kinematic analysis system (Vicon, Oxford, UK), comprised of six infrared cameras and four force plates (Advanced Mechanical Technology Inc., (AMTI), Watertown, MA, USA), was used. Before conducting kinematic analysis, reflective spheres referred to as "markers" or passive infrared reflection markers were attached to the subject, as depicted in Figure 2a. The Vicon system required calibration before capturing actual motion to accurately model the spatial relationships between the cameras. Upon

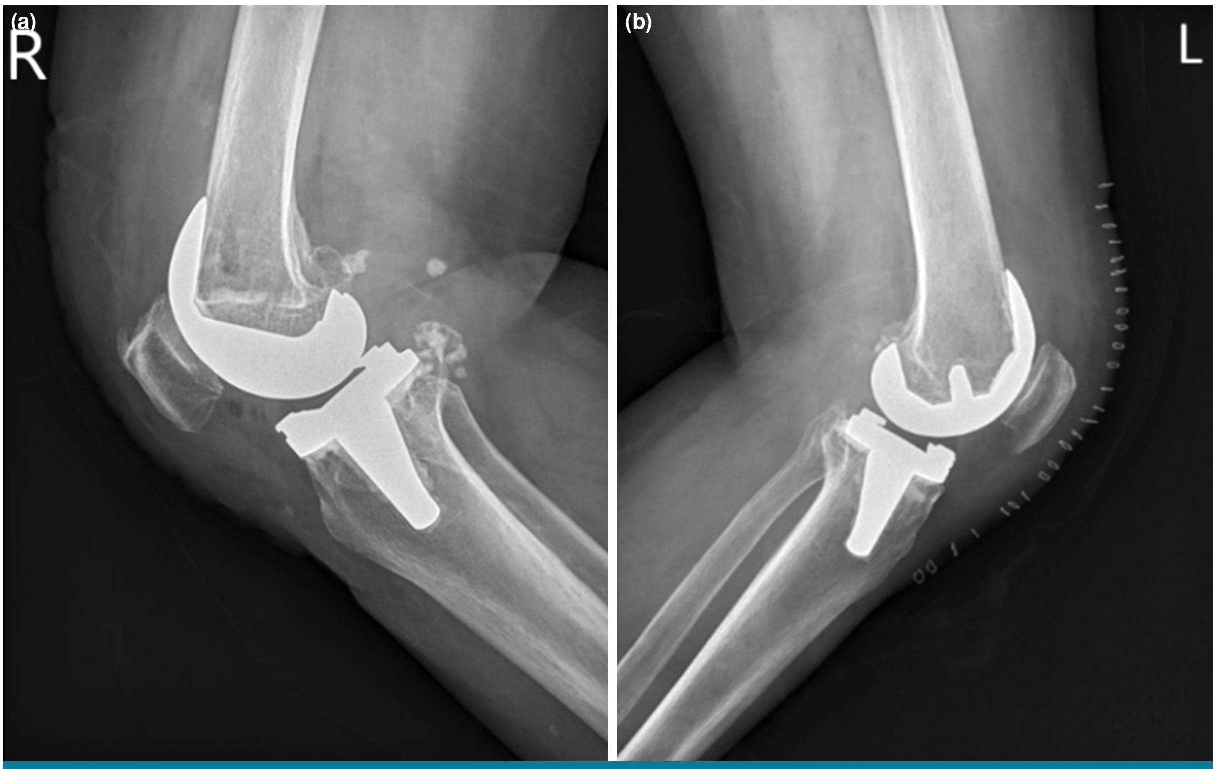


FIGURE 1. Radiograph of the knee joint after **(a)** PS TKA and **(b)** CR TKA.
PS: Posterior-stabilized; TKA: Knee arthroplasty; CR: Cruciate-retaining.

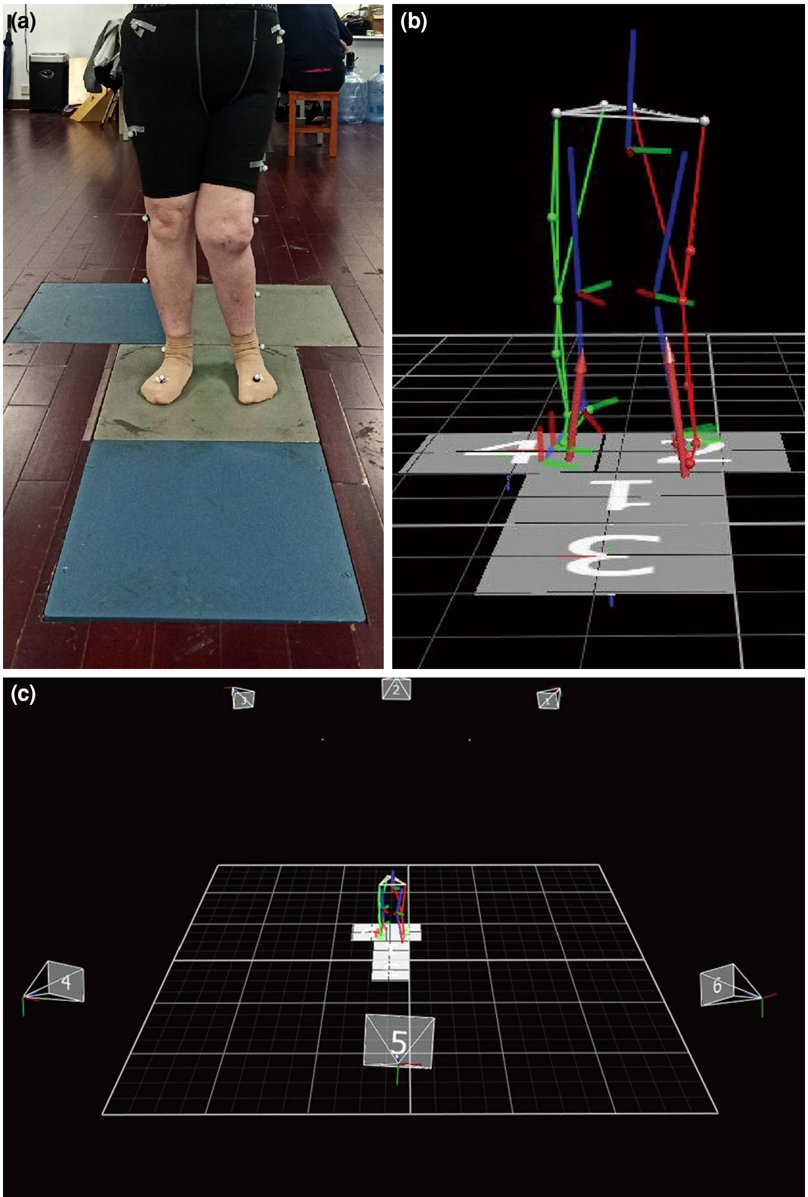
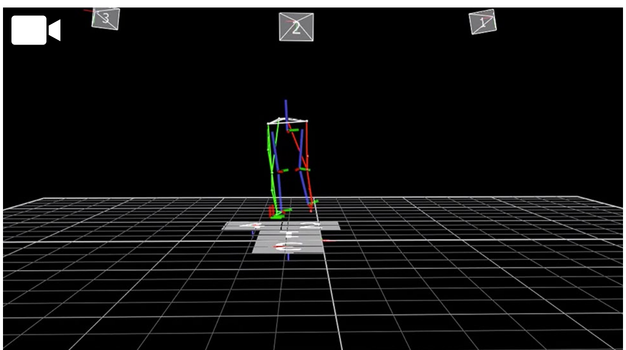


FIGURE 2. Kinematic analysis with the Vicon system. **(a)** The scene during a participant's kinematic analysis. **(b, c)** Three-dimensional view after dynamic modeling.



VIDEO 1. Three-dimensional kinematic dynamic model of a participant.

calibration, the subject was instructed to walk within a designated area to ensure natural and smooth movement, closely replicating everyday walking patterns. The system's high-speed camera concurrently recorded the positions of these markers on the subject's body. Data from six complete gait cycles were collected from each subject for 3D dynamic modeling (Figures 2b, c; Video 1). Basic gait parameters analyzed included cadence, stride time, opposite foot off, opposite foot contact, step time, single support, double support, foot off, stride length, step are length, and walking speed. All mechanical data were collected by AMTI

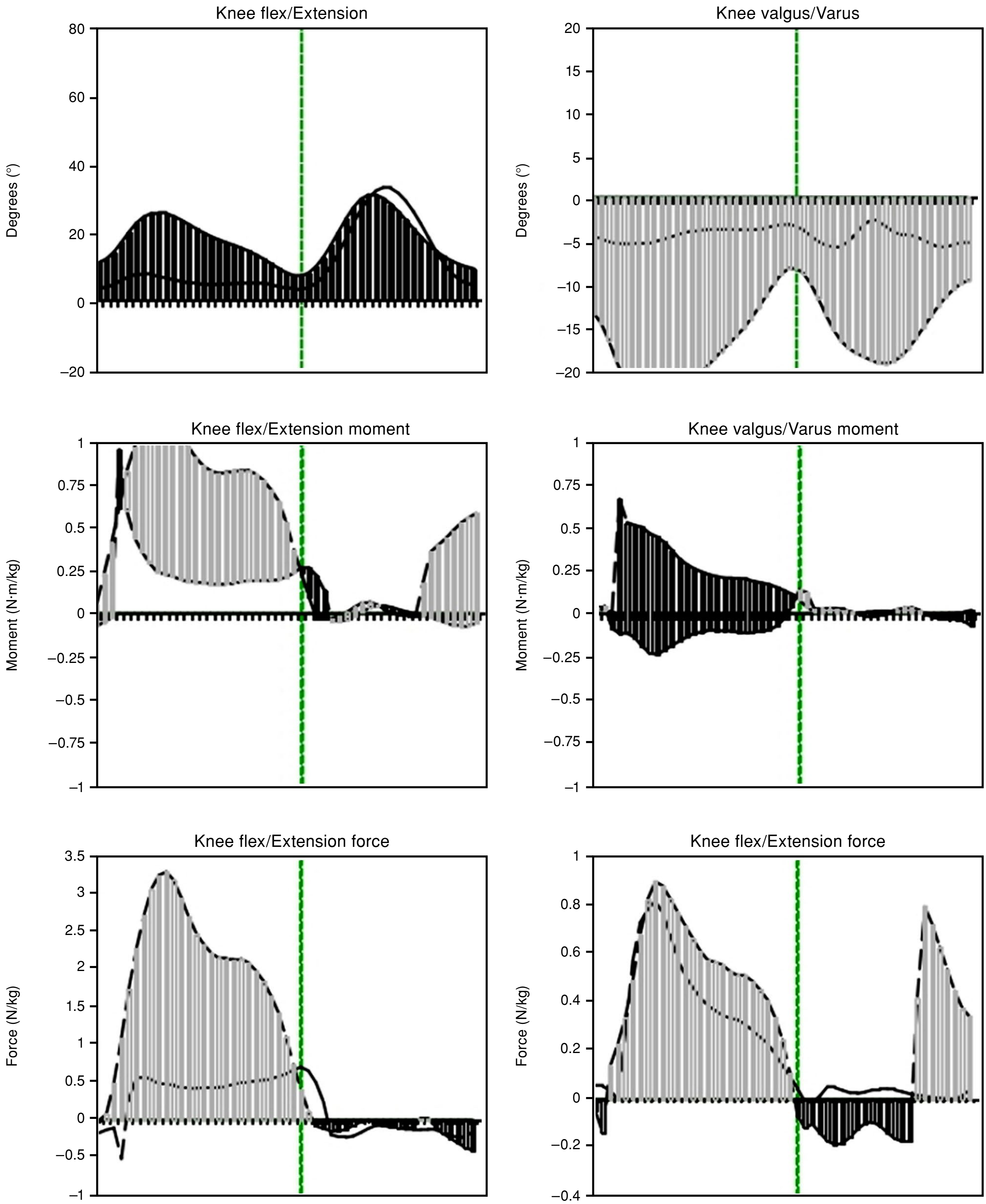


FIGURE 3. Some of a patient's gait parameters are displayed. The abscissa represents a gait cycle. **(a)** The ordinate represents the knee angle. **(b)** The ordinate represents the knee moment. **(c)** The ordinate represents knee force.

force plates. Nexus software (Nexus Software LLC Inc., Chesterland, OH, USA) was used to process and analyze the obtained results, and a dynamic mechanical model of the lower limb was built in combination with the optical capture system.[21,22] Kinematic characteristics of the knee joint were also measured, encompassing 3D dynamic angle, moment, and force at flexion, extension, adduction, abduction, and internal and external rotation (Figure 3).

Quantization for knee stability

The dynamic range of the hip-knee-ankle (HKA) angle signified the knee's dynamic stability.[23] The dynamic HKA angle was directly derived from the 3D kinematic analysis, and the instrument directly determined the angle changes during gait. As shown in Figure 3a, the knee valgus/varus angle was determined by the midpoint of the hip, knee, and ankle joint, which is the dynamic HKA angle. Moreover, the system differentiated between extension and flexion stability based on the knee joint's varying motion states. This range indicated extension stability during the stance phase and flexion stability throughout the swing phase.

Clinical assessment

The static HKA angle was measured from lower extremity radiographs taken while standing. This angle between the midpoint of the hip, knee, and ankle joints is positive for varus and negative for valgus. Passive knee ROM was measured using a standard goniometer. The patient was positioned supine with the hip in neutral alignment. The goniometer was aligned with the lateral epicondyle of the femur, the greater trochanter, and the lateral malleolus. The examiner passively flexed and extended the patient's knee, recording the maximum angles of knee flexion and extension. The Hospital for Special Surgery (HSS) knee score of each participant before and six months after surgery was assessed. The HSS knee score was calculated by two surgeons with more than five years of experience in orthopedic surgery, and the final score was the average of the two measurements. If the difference was greater than 5 points, a senior physician was responsible for reevaluation.

Statistical analysis

The sample size was analyzed by G*power version 3.1 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Based on our previous study,[23] we anticipated that the mean knee stability during gait for PS and CR implants would be 1.221±1.258 and 2.811±2.351, respectively. Knee stability was chosen because it is one of the most important indicators to evaluate after TKA.[24-26] Assuming a bilateral significance level of 5% and 90% power, each group required 31 participants. We planned to divide the participants into two groups, with each group containing at least 31 participants. We conducted post hoc power analysis on the main gait parameter of knee joint stability, with a power

TABLE I
Participant characteristics

	PS group		CR group		Control group		
Variables	n	Mean±SD	n	Mean±SD	n	Mean±SD	*p*
Age (year)		69.54±7.49		67.85±8.77		64.50±2.93	0.334
Sex							-
Males	10		11		9		
Females	47		22		19		
Height (cm)		157.67±7.08		160.18±7.60		160.11±7.14	0.118
Weight (kg)		64.27±10.76		67.12±9.42		64.62±10.64	0.209
BMI (kg/m^2)		25.82±3.69		26.11±2.85		25.14±3.23	0.691
Surgical site							-
Right	35		21		-		
Left	22		12		-		
Hip-knee-ankle (°)		9.98±5.23		8.11±4.45		-	0.087
Range of motion (°)		111.79±16.67		114.30±16.64		-	0.492
Preoperative HSS score		65.07±9.74		64.45±9.70		-	0.773
Postoperative HSS score		85.21±6.540		86.73±5.246		-	0.259

PS: Posterior-stabilized; CR: Cruciate-retaining; SD: Standard deviation; BMI: Body mass index; HSS: Hospital for Special Surgery Knee Score.

(1-β error probability) of 0.96, indicating a reasonable sample size.

Data were analyzed using SPSS version 11.0 software (SPSS Inc., Chicago, IL, USA). Initially, we conducted an independent sample t-test to assess the differences between the groups. Subsequently, a one-way analysis of variance was performed to evaluate whether significant differences existed in the mean values across the groups. Post hoc comparisons among the three groups were conducted using the least significant difference test. A p-value <0.05 was considered statistically significant.

RESULTS

Table I displays the baseline characteristics of the three groups. There were no significant differences among the groups in terms of age, height, weight, body mass index, static HKA angle, passive ROM, and preoperative and postoperative HSS knee scores ($p>0.05$). Some patients with severe knee dysfunction (low HSS score) could not complete gait collection and were not included in this trial, which may have resulted in the mean preoperative HSS score being >60.

Table II compares the basic gait parameters of different implants before and after surgery, including cadence, stride time, opposite foot off, opposite foot contact, step time, single support period, double support period, foot off, stride length, step length, and walking speed. Before surgery, there were no significant differences in basic gait parameters between the PS and CR groups. However, the postoperative basic gait parameters of the PS group exhibited considerable changes compared to the CR group. Significant alterations were observed in the PS group for cadence ($p=0.046$), stride time ($p=0.011$), opposite foot off ($p<0.001$), opposite foot contact ($p=0.038$), step time ($p=0.005$), double support period ($p<0.001$), and foot off ($p=0.004$). In the CR group, significant changes were noted in opposite foot off ($p=0.002$) and foot off ($p<0.001$).

Table III presents the knee kinematic characteristics during the gait cycle before TKA. There were no statistically significant differences in the preoperative knee kinematic characteristics between the PS and CR groups, with the exceptions of knee flexion angle and dynamic ROM. Moreover, notable differences in preoperative knee stability were observed between the two groups. Table IV indicates that postoperative kinematic characteristics between the PS and CR groups did not significantly

TABLE II

Comparison of preoperative and postoperative basic gait parameters

	PS group (n=57)			CR group (n=33)			Control group (n=28)	PS *vs.* Control		CR *vs.* Control		PS *vs.* CR	
	Before	After		Before	After			Before	After	Before	After	Before	After
	Mean±SD	Mean±SD	*p*	Mean±SD	Mean±SD	*p*	Mean±SD	*p*	*p*	*p*	*p*	*p*	*p*
Cadence (step/min)	87.69±16.22	92.58±10.48	0.046*	89.76±16.89	91.86±10.97	0.537	108.47±10.35	<0.001***	<0.001***	<0.001***	<0.001***	0.537	0.756
Stride time (s)	1.42±0.31	1.31±0.15	0.011*	1.39±0.30	1.33±0.17	0.288	1.12±0.11	<0.001***	<0.001***	<0.001***	<0.001***	0.545	0.612
Opposite foot off (%)	14.56±3.61	11.67±1.86	<0.001***	14.28±3.71	11.79±1.91	0.002**	10.25±2.17	<0.001***	0.002**	<0.001***	0.003**	0.698	0.780
Opposite foot contact (%)	48.97±2.46	49.73±1.88	0.038*	49.84±1.98	49.54±1.48	0.508	49.80±1.25	0.090	0.852	0.947	0.531	0.063	0.590
Step time (s)	0.73±0.16	0.66±0.08	0.005**	0.70±0.15	0.67±0.10	0.395	0.56±0.06	<0.001***	<0.001***	<0.001***	<0.001***	0.333	0.520
Single support period (s)	0.49±0.12	0.50±0.06	0.584	0.48±0.11	0.50±0.06	0.609	0.42±0.06	0.007**	<0.001***	0.015**	<0.001***	0.981	0.943
Double support period (s)	0.40±0.13	0.30±0.06	<0.001***	0.41±0.17	0.31±0.09	0.009	0.23±0.05	<0.001***	<0.001***	<0.001***	<0.001***	0.902	0.508
Foot off (%)	62.37±3.40	60.93±2.09	0.004**	63.96±3.19	60.97±1.93	<0.001***	60.29±2.65	0.005**	0.209	<0.001***	0.228	0.024*	0.926
Stride length (m)	0.69±0.20	0.71±0.14	0.438	0.77±0.20	0.76±0.18	0.893	1.07±0.10	<0.001***	<0.001***	<0.001***	<0.001***	0.053	0.101
Step length (m)	0.33±0.10	0.35±0.08	0.394	0.37±0.11	0.38±0.09	0.645	0.54±0.05	<0.001***	<0.001***	<0.001***	<0.001***	0.078	0.053
Walking speed (m/s)	0.51±0.19	0.55±0.12	0.208	0.59±0.23	0.59±0.16	0.873	0.97±0.15	<0.001***	<0.001***	<0.001***	<0.001***	0.070	0.202

PS: Posterior-stabilized; CR: Cruciate-retaining; SD: Standard deviation; * The *p* value was significant at the 0.05 level; ** The *p* value was significant at the 0.01 level; *** The *p* value was significant at the 0.001 level.

TABLE III
Knee kinematic characteristics during the gait cycle before TKA

	PS group (n=57)	CR group (n=33)	PS *vs.* CR	PS *vs.* CR
	Mean±SD	Mean±SD	t	*p*
Extension moment (N·m/kg)				
Maximum during gait	0.853±1.851	0.616±0.309	0.730	0.468
Mean during gait	0.345±0.381	0.305±0.189	0.574	0.568
Maximum flexion moment (N·m/kg)	–0.562±2.723	–0.234±0.346	–0.687	0.494
Adduction moment (N·m/kg)				
Maximum during gait	0.604±1.554	0.423±0.264	0.661	0.510
Mean during gait	0.226±0.367	0.182±0.119	0.665	0.508
Internal rotation moment (N·m/kg)				
Maximum during gait	1.044±6.740	0.173±0.135	0.741	0.461
Mean during gait	0.212±1.223	0.056±0.038	0.732	0.466
Maximum external rotation moment (N·m/kg)	–0.686±4.746	–0.057±0.058	–0.760	0.449
Extension force (N/kg)				
Maximum during gait	2.870±3.265	2.468±1.077	0.685	0.495
Mean during gait	1.424±0.685	1.388±0.626	0.245	0.807
Flexion force (N/kg)				
Maximum during gait	–1.038±3.041	–0.687±0.608	–0.654	0.515
Mean during gait	–0.278±0.437	–0.276±0.216	–0.027	0.979
Maximum adduction force (N/kg)	1.218±2.531	0.811±0.588	0.909	0.366
Maximum internal rotation force (N/kg)	1.003±2.261	0.748±0.749	0.627	0.532
External rotation force (N/kg)				
Maximum during gait	–8.546±1.579	–8.269±1.550	–0.807	0.422
Mean during gait	–5.781±1.075	–5.591±1.282	–0.754	0.453
Maximum flexion angle (°)	34.172±14.507	43.124±17.570	–2.608	0.011*
Dynamic ROM (°)	28.572±17.325	38.427±11.869	–3.191	0.002**
Knee extension stability	1.821±1.100	2.453±1.392	–2.378	0.020*
Knee flexion stability	3.811±2.729	6.657±4.015	–3.617	0.001**

TKA: Knee arthroplasty; PS: Posterior-stabilized; CR: Cruciate-retaining; SD: Standard deviation; ROM: Range of motion; * The *p* value was significant at the 0.05 level; ** The *p* value was significant at the 0.01 level.

differ, except in the dynamic ROM of the knee joint during gait following TKA. Nevertheless, both the PS and CR groups exhibited significant variations in several postoperative kinematic characteristics of the knee joints, including flexion moment, adduction moment, extension force, flexion force, internal rotation force, external rotation force, maximum flexion angle, dynamic ROM, and knee stability, compared to healthy controls.

DISCUSSION

Postoperative knee kinematic characteristics following PS and CR TKA remained inferior to those of healthy controls. Nevertheless, the patient groups exhibited enhanced dynamic stability. Significant changes in gait patterns were observed after PS and CR TKA; however, neither group recovered to a healthy state. The gait after CR TKA was closer to the OA state. This study increases the understanding of kinematics and contact mechanics in the postoperative gait cycles associated with different TKA implant designs and offers comprehensive insights into normal knee joint function.

The analysis of gait patterns mainly relies on the basic kinematic parameters, including cadence (step/min), stride time (sec), opposite foot off (%), opposite foot contact (%), step time (sec), single support period (sec), double support period (sec), foot off (%), stride length (m), step length (m), and walking speed (m/sec). As indicated

TABLE IV
Knee kinematic characteristics during the gait cycle after TKA

	PS group (n=57)	CR group (n=33)	Control group (n=28)	PS *vs.* Control	CR *vs.* Control	PS *vs.* CR
	Mean±SD	Mean±SD	Mean±SD	*p*	*p*	*p*
Extension moment (N·m/kg)						
Maximum during gait	0.624±0.292	0.537±0.285	0.520±0.370	0.148	0.830	0.201
Mean during gait	0.278±0.152	0.243±0.158	0.218±0.148	0.092	0.524	0.301
Maximum flexion moment (N·m/kg)	0.181±0.168	0.177±0.131	0.337±0.135	<0.001***	<0.001***	0.880
Adduction moment (N·m/kg)						
Maximum during gait	0.333±0.215	0.319±0.158	0.399±0.231	0.168	0.132	0.750
Mean during gait	0.127±0.068	0.128±0.061	0.180±0.120	0.005*	0.014*	0.947
Internal rotation moment (N·m/kg)						
Maximum during gait	0.105±0.073	0.109±0.054	0.114±0.090	0.583	0.760	0.825
Mean during gait	0.033±0.018	0.035±0.018	0.043±0.038	0.053	0.166	0.672
Maximum external rotation moment (N·m/kg)	0.447±0.426	0.040±0.315	0.043±0.062	0.905	0.791	0.663
Extension force (N/kg)						
Maximum during gait	1.811±0.853	1.790±1.049	3.116±0.663	<0.001***	<0.001***	0.912
Mean during gait	1.028±0.578	1.019±0.669	1.620±0.454	<0.001***	<0.001***	0.947
Flexion force (N/kg)						
Maximum during gait	0.545±0.293	0.537±0.281	0.716±0.216	0.008**	0.012*	0.892
Mean during gait	0.247±0.113	0.228±0.082	0.303±0.049	0.010*	0.002**	0.359
Maximum adduction force (N/kg)	0.532±0.478	0.521±0.475	0.417±0.477	0.295	0.397	0.911
Maximum internal rotation force (N/kg)	0.546±0.349	0.622±0.227	0.845±0.109	<0.001***	0.002**	0.211
External rotation force (N/kg)						
Maximum during gait	8.310±1.507	8.256±1.211	9.029±1.340	0.027*	0.033*	0.860
Mean during gait	5.586±1.051	5.826±1.081	6.431±0.980	0.001**	0.026*	0.296
Maximum flexion angle (°)	36.423±14.973	35.470±16.565	58.802±9.385	<0.001***	<0.001***	0.762
Dynamic ROM (°)	12.123±7.620	20.199±10.477	53.701±7.217	<0.001***	<0.001***	<0.001***
Knee extension stability	2.043±0.990	1.563±1.001	3.615±2.276	<0.001***	<0.001***	0.120
Knee flexion stability	4.356±2.846	4.183±3.553	9.299±6.521	0.001**	0.001**	0.850

TKA: Knee arthroplasty; PS: Posterior-stabilized; CR: Cruciate-retaining; SD: Standard deviation; ROM: Range of motion; * The *p* value was significant at the 0.05 level; ** The *p* value was significant at the 0.01 level; *** The *p* value was significant at the 0.001 level.

in Table II, the CR group's postoperative gait pattern and basic gait parameters remained consistent with preoperative values, and the gait pattern significantly changed after PS TKA. We acknowledge that not all statistically significant differences necessarily imply clinically meaningful effects. This result might also be attributed to the removal of the PCL in PS TKA. The primary function of the PCL is to prevent excessive backward movement of the tibia. It is associated with the proprioception of the knee joint and the movement and position of the knee joint.[27] Removal of the PCL reduces knee joint proprioception and leads to the "forgetting" of the previous gait pattern, and a new gait pattern is gradually established during postoperative recovery. Our study supports the idea that preserving the PCL more closely aligns with the physiological structure and kinematic principles of the human body.[28] Shu et al.[29] demonstrated through finite element analysis that the contradicting movements of the knee joint in anterior and posterior directions after PS TKA were more pronounced, indicating greater discomfort with PS implants among patients. Our results showed that the dynamic ROM of the knee in the CR group was significantly greater than that in the PS group, suggesting that CR TKA provided greater dynamic ROM during gait. Matsuda et al.[30] documented anterior and posterior tibial displacement in patients a decade after TKA, revealing that approximately 50% of CR TKA patients exhibited suboptimal anteroposterior stability. This might suggest that the low anteroposterior stability after CR TKA contributes to increased dynamic ROM during gait. Furthermore, there were no significant differences in the other kinematic characteristics between PS and CR TKA.

The HSS knee scores of PS and CR TKA improved significantly, with no statistical difference between the groups, indicating that both prostheses can significantly improve knee joint function. Our findings indicate that knee extension force, flexion moment, and force following TKA are significantly lower compared to those of healthy individuals, implying that recovery of knee extension and flexion functions is challenging six months after TKA. However, the flexion and extension function may recover better during long-term follow-up. The postoperative adduction moment was also notably reduced; this moment reflects the medial compartment pressure.[31] Hajduk et al.[32] conducted a 3D kinematic analysis on 42 knee joints after TKA and observed that the kinematic characteristics of patients who received TKA were inferior relative to healthy individuals, resembling the kinematic characteristics of knee OA. The knee joint adduction moment directly represents the force exerted on the knee joint. The postoperative kinematic analysis of both PS and CR TKA suggested that both implant designs could maintain an optimal balance of medial and lateral knee joint spaces. Götz et al.[33] compared the postural stability of 20 knee joints that underwent PS TKA with 20 that received CR TKA using the Biodex Balance System. The findings indicated no significant differences in postural stability between the PS and CR groups. In this study, knee joint stability was quantified using a 3D motion system, providing an accurate reflection of stability changes in the knee joint. The results demonstrated that both postoperative extension and flexion stability were more stable compared to those in a healthy population. This greater stability may be attributed to optimal soft tissue balance achieved during surgery or the increased caution patients exhibited in using their new joints, thereby enhancing joint stability.

This study had several limitations. First, the sample sizes of the PS, CR, and healthy control groups differed, potentially introducing bias. Further research should aim to equalize the sample sizes across groups. Second, the follow-up period was limited to only six months. It is undeniable that increasing follow-up time may lead to more changes in kinematic characteristics, which could affect the conclusion. Third, despite rigorous data analysis, some relevant variables may have been overlooked, such as deformity of the contralateral limb and soft tissue contracture. Finally, the research being conducted at a single center may restrict the external validity of the findings. Future studies involving larger, more diverse populations and multicenter collaboration are required to corroborate our results.

In conclusion, this study utilized 3D kinematic analysis to compare PS and CR implants. The gait pattern underwent significant alterations following PS TKA, whereas the gait pattern closely resembled the physiological state after CR TKA. Although knee kinematic function remained inferior to that of healthy counterparts of the same age, both patient groups exhibited improvements in knee dynamic stability.

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Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Is responsible for designing the research program, determining the method and process of the experiment, collecting and recording the experimental data, and ensuring the accuracy and integrity of the data: C.G.; Participated in the processing and analysis of the data and explained and discussed the results. Responsible for the review and analysis of relevant literature, and determining the theoretical basis and background of the research: X.L.; Participated in the statistical analysis of the experimental data and was responsible for interpreting the relevant results of the data: H.L., B.Y.; Participated in the review and editing of the article put forward valuable revision opinions and suggestions, and provided financial support for the experiment: M.F.; Participated in the operation and management of the experiment, assisted in the process of data collection and processing, and explained and discussed the experimental data, which provided important support for the conclusion of the paper: W.L. All authors read and approved the final manuscript.

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