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Comparing Outcomes of Bicruciate-Stabilized and Cruciate-Retaining Total Knee Arthroplasty

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Background: Bicruciate-stabilized (BCS) total knee arthroplasty (TKA) aims to restore normal kinematics by replicating the function of both cruciate ligaments. Conventional cruciate-retaining (CR) design in TKA has shown previous clinical success with lower complication rates. This study compared the patient-reported outcomes between the BCS and CR TKA designs.

Methods: This retrospective study examined patients who underwent primary TKA using a CR or a BCS implant. Patient demographics, Knee Injury and Osteoarthritis Outcome Score for Joint Replacement (KOOS, JR), and Forgotten Joint Score (FJS) were compared between two cohorts. Patient-reported outcome measures were analyzed using independent samples *t*-tests.

Results: There were no significant preoperative demographic differences between groups. The CR cohort (n = 756) had significantly higher average KOOS, JR Scores compared to the BCS cohort (n = 652) at 3 months (59.7 ± 3.8 vs. 53.0 ± 3.9, $p < 0.001$) and 2 years (62.6 ± 8.0 vs. 53.8 ± 6.7, $p = 0.001$) after TKA. Within the cohort, KOOS, JR delta differences were not significant for CR when comparing patient scores 3 months to 1 year after surgery. Meanwhile, the BCS patients did show significant delta improvement (4.1 ± 1.9, $p = 0.030$) when compared 3 months to 1 year after surgery. One year postoperatively, the BCS cohort (n = 134) showed a significantly higher average FJS score (49.5 ± 31.4, vs. 36.8 ± 28.5, $p = 0.028$) than the CR cohort (n = 203). Both cohorts displayed a significant difference in delta improvements within their respective cohort when measuring FJS from 3 months to 1 year, 2 years, and 3 years after surgery.

Conclusions: The CR cohort performed better on average, compared to the BCS cohort in measures of KOOS, JR scores at the 2-year follow-up. The BCS cohort performed marginally better regarding FJS only at 1-year follow-up.

Keywords: *Total knee arthroplasty, Knee prostheses, Patient reported outcomes*

Total knee arthroplasty (TKA) is the recommended course of treatment for advanced knee arthritis and is one of the most commonly performed surgical procedures in the United States.[1-3] It is estimated that over three million of these procedures will be performed within the decade.[4] With a wide prevalence of operations performed also comes a wide range of implant designs surgeons can choose from; with much discussion among which implant designs to choose from.[5] Among the designs used during TKA, the cruciate-retaining (CR) and bicruciate-stabilized (BCS) lay at the forefront. Without a clear difference in performance between the implants, patient indications and surgeon preference and experience often dictate which design will be used.[5,6]

By not requiring the creation of a box, CR implants preserve the bone stock and are more naturally able to reproduce femoral rollback on the tibia during flexion.[7] Furthermore, by retaining the posterior cruciate ligament (PCL), CR implants theoretically contribute to a greater range of motion (ROM) due to the reproduction

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of femoral rollback.[8] However, CR TKA may not be recommended with PCL insufficiency, previous trauma, or severe deformity.[6] Despite the ability to produce femoral rollback, the CR design cannot fully reproduce native knee kinematics due to the resection of the anterior cruciate ligament (ACL); the same is true for the posterior-stabilized (PS) TKA.[9] Furthermore, both conventional TKA bearings tend to result in paradoxical sliding,[10] which has been suggested to result in the loss of knee flexion.[11]

The BCS TKA design differs from previous conventional designs as it attempts to reproduce the patient's native knee kinematics, including ligament tensioning and knee rollback,[12] thereby reducing mediolateral instability in the mid-flexion range and improving patient satisfaction.[10] Furthermore, sacrificing the PCL in BCS design may increase the conformity of the prosthesis and can lead to decreased contact stresses and polyethylene wear.[8] The tibial insert in the BCS-TKA is designed with a concave medial and convex lateral shape that increases anterior-posterior stability throughout knee flexion favoring a native kinematic pattern.[13] This physiological matching that the BCS implant tries to achieve may yield promising and, in some cases, superior clinical findings in studies.[9,14]

While both implants have been evaluated using clinical outcomes, patient satisfaction is scarcely reported alongside clinical outcomes despite it being a well-known issue among TKA recipients.[15-18] A novel method of quantifying patient satisfaction is the Forgotten Joint Score (FJS), which allows patients to give a subjective report as to how natural their implant feels after operation.[19] Using the FJS to compare different TKA designs has been completed previously, although showing no significant differences between CR and PS implants.[20]

In order to compare the two implant designs more fully, we aimed to compare the differences using the Knee Injury and Osteoarthritis Outcome Score for Joint Replacement (KOOS, JR) as well as patient satisfaction using the FJS. We hypothesized that there would be no significant differences between the BCS and CR implant designs.

METHODS

Before any study procedures took place, NYU School of Medicine Institutional Review Board (FWA# 00004952) approval was obtained with a waiver of consent due to the retrospective nature of the study.

Patient Selection

We conducted a retrospective review of all patients who received a primary, elective TKA at our hospital from 2015 to 2021 and had at least 2 years of clinical follow-up. Patients were separated into two cohorts based on the utilized implant design: cruciate-retaining TKA System (Journey II system, Smith & Nephew) was included in the CR implant group and bicruciate-stabilized TKA (Smith & Nephew) in the BCS group.

In all reported cases in this study, surgeons opted for a standard medial parapatellar approach with the goal to recreate neutral mechanical alignment whilst causing the least amount of constraint to achieve stability. The surgical indications for CR or BCS at our institution are derived from the physical exam, radiographic evaluation, intraoperative findings, and surgeon preference. For the purposes of this study, the primary indication for patients who received a TKA was osteoarthritis. The use of CR or BCS was determined by the surgeon. Ultimately, the physician's intraoperative assessment, preference, pertinent patient history, physical exam, and radiographic findings resulted in the decision between implants.

For this study, 1,855 patients who received a TKA with osteoarthritis as their primary indication were identified. Three hundred and fifty-three patients (19%) were excluded because they received a different implant design not analyzed in the scope of this study. One hundred patients (5.3%) were lost to follow-up, leaving a total of 1,402 patients included in the study. Of those, 646 patients (46%) received the CR implant, 55 of whom received bilateral TKA, resulting in a total of 756 knees included in the analysis. Specifically, 112 knees were included from patients who had completed their 2-year follow-up and 115 from those who had completed their 1-year follow-up. Five hundred and eighty-six (42%) patients received the BCS implant, 33 of whom received bilateral TKA resulting in a total of 652 knees included in the analysis. Specifically, 118 knees were analyzed from patients who had completed their 2-year follow-up and 112 from those who had completed the 1-year follow-up.

Data Collection

Demographic data including sex, age, smoking status, race, American Society of Anesthesiologists (ASA) score, body mass index (BMI; kg/m^2), Charlson Comorbidity Index, length of stay (LOS; days), and surgical time (hours) were collected for all patients from the electronic patient medical record system (Epic Caboodle ver. 15) using Microsoft SQL Server Management Studio 2017. LOS is described as the total number of hours in the hospital after surgery, and surgical time was the difference between initial skin incision and closure. Patients were followed up postoperatively at a series of time points: 2 weeks, 12 weeks, 1 year, 2 years,

and 3 years. Data from up to the 3-year follow-up were not included for KOOS, JR scores.

Outcome Measures

In this study, patient-reported outcomes (PROS) were measured by the Knee Injury Osteoarthritis Survey (KOOS, JR) and FJS. PROS were collected preoperatively and again during subsequent follow-up visitations at 12 weeks, 1 year, 2 years, and 3 years postoperatively. Other assessments such as radiological evaluation and ROM were not in the scope of this study, and as such were not included as outcome measures partly as they are not documented in an objective manner that can be compared across surgeons. There was no significant difference in all-cause or aseptic revision rates for either group (Table 1). At baseline, there were no significant differences regarding sex, age, smoking status, race, ASA score, or BMI (Table 1). While there was no significant difference in average surgical time between cohorts, the CR cohort had a significantly shorter LOS compared to the BCS cohort (2.1 ± 1.6 vs. 2.4 ± 1.9, $p = 0.002$). There were also no significant differences between groups regarding all-cause and aseptic revision rates. The CR group had an all-cause revision rate of 2.9% and the BCS group had a revision rate of 4% (Table 1). There was no significant difference in all-cause or aseptic revision rates for either group (Table 1).

Statistical Analysis

All data were organized using Microsoft Excel software (Microsoft Corp.). A binary variable was created to identify patients who underwent TKA with BCS or CR prostheses. Binary variables were also created to group patients' postoperative dates. Study participants' demographic and clinical baseline characteristics were described as means with standard deviations for continuous variables and frequencies with percentages for categorical variables. KOOS, JR and FJS scores were described as means with a standard error of difference. Statistical differences in continuous variables were detected using independent samples *t*-tests. A *p*-value less than 0.05 was considered statistically significant.

RESULTS

At baseline, there were no significant differences regarding sex, age, smoking status, race, ASA score, or BMI (Table 1). While there was no significant difference in average surgical time between cohorts, the CR cohort had a significantly shorter LOS compared to the BCS cohort (2.1 ± 1.6 vs. 2.4 ± 1.9, $p = 0.002$). There were also no significant differences between groups regarding all-cause and aseptic revision rates. The CR group had an all-cause revision rate of 2.9% and the BCS group had a revision rate of 4% (Table 1).

Preoperatively, there were no significant differences between the CR and BCS cohorts in terms of KOOS, JR scores. The CR cohort had a significantly higher average KOOS, JR score than the BCS cohort postoperatively at the 3-month (59.7 vs. 53.0, $p = 0.0001$) and 2-year (62.6 vs. 53.8, $p = 0.001$) postoperative follow-ups (Table 2). When comparing delta improvements in KOOS, JR between groups, the CR cohort had a significantly (14.5 ±

Table 1. Demographic Data

Variable	CR (n = 646)	BCS (n = 586)	*p*-value
Sex			0.242
Male	245 (38.1)	285 (37.7)	
Female	401 (61.9)	471 (62.3)	
Age (yr)	62.5 ± 9.6	62.6 ± 8.5	0.374
Smoking status			0.477
Never	348 (54)	340 (58)	
Former	232 (36)	187 (32)	
Current	64 (10)	53 (9)	
Unknown	32 (0.5)	6 (1)	
Race			0.300
White	303 (47.8)	286 (48.9)	
Black or African American	129 (20.5)	140 (23.9)	
Asian	38 (5.9)	35 (6.0)	
Other	168 (25.9)	124 (21.2)	
ASA score			0.495
1	17 (2.7)	22 (3.8)	
2	414 (64.1)	336 (57.3)	
3	208 (32.2)	219 (37.4)	
4	6 (1.0)	9 (1.5)	
BMI (kg/m^2)	32.8 ± 6.6	32.5 ± 6.0	0.216
Length of stay (day)	2.1 ± 1.6	2.4 ± 1.9	0.002*
Surgical time (hr)	1.8 ± 0.5	1.7 ± 0.5	0.640
All-cause revision rate (%)	2.9	4.0	0.896
Aseptic revision rate (%)	2.2	3.2	0.932

Values are presented as number (%) or mean ± standard deviation.
CR: cruciate-retaining, BCS: bicruciate-stabilized, ASA: American Society of Anesthesiologists, BMI: body mass index.
*Statistically significant result.

Table 2. KOOS, JR Score Comparison

KOOS, JR score	CR (n = 756)	BCS (n = 652)	*p*-value
Preop	45.2 ± 4.1	43.5 ± 4.8	0.288
3 mo	59.7 ± 3.8	53.0 ± 3.9	< 0.001*
1 yr	59.8 ± 6.4	57.1 ± 7.0	0.264
2 yr	62.6 ± 8.0	53.8 ± 6.7	0.001*
Delta improvement			
Preop to 3 mo	14.5 ± 1.4	9.5 ± 1.6	0.020*
Preop to 1 yr	13 ± 2.9	13.6 ± 2.1	0.856
Preop to 2 yr	9 ± 2.4	10.3 ± 2.0	0.675
3 mo to 1 yr	0.1 ± 1.8	4.1 ± 1.9	0.134
1 yr to 2 yr	0.3 ± 2.6	3.3 ± 2.4	0.399

Values are presented as mean ± standard error difference.
KOOS, JR: Knee Injury and Osteoarthritis Outcome Score for Joint Replacement, CR: cruciate-retaining, BCS: bicruciate-stabilized, Preop: preoperative.
*Statistically significant result.

Table 3. KOOS, JR Score Delta Improvements

Delta improvement	Mean ± SED	*p*-value
CR		
Preop to 3 mo	14.5 ± 1.4	< 0.001*
Preop to 1 yr	13 ± 2.9	< 0.001*
3 mo to 1 yr	0.1 ± 1.8	0.942
BCS		
Preop to 3 mo	9.5 ± 1.6	< 0.001*
Preop to 1 yr	13.6 ± 2.1	< 0.001*
3 mo to 1 yr	4.1 ± 1.9	0.030*

KOOS, JR: Knee Injury and Osteoarthritis Outcome Score for Joint Replacement, SED: standard error difference, CR: cruciate-retaining, Preop: preoperative, BCS: bicruciate-stabilized.
*Statistically significant result.

1.4 vs 9.5 ± 1.6, $p = 0.0196$) higher improvement than the BCS group when comparing their preoperative scores to 3-month postoperative scores (Table 2).

In terms of KOOS, JR scores, the CR cohort experienced significant improvement from their preoperative values to 3 months ($p < 0.0001$) and 1 year ($p < 0.0001$) of postoperative follow-ups (Table 3). The BCS cohort also experienced significant improvement from their preoperative values to their 3-month ($p < 0.0001$) and 1-year ($p < 0.0001$) postoperative follow-ups (Table 3). As opposed to the CR cohort, the BCS cohort also showed a significant improvement when comparing their 3-month and 1-year postoperative values ($p = 0.030$).

Table 4. FJS Comparison

FJS	CR (n = 203)	BCS (n = 134)	*p*-value
3 mo	27.6 ± 26.1	24.2 ± 25.0	0.506
1 yr	36.8 ± 28.5	49.5 ± 31.4	0.028*
2 yr	44 ± 30.3	56.3 ± 33.7	0.099
3 yr	61.9 ± 27	52.1 ± 29.7	0.337
Delta improvement			
3 mo to 1 yr	9.2 ± 4.6	25.3 ± 6.2	0.037*
3 mo to 2 yr	16.4 ± 5.1	32.1 ± 7.1	0.072
3 mo to 3 yr	34.3 ± 7.6	27.9 ± 7.4	0.567

Values are presented as mean ± standard error difference.
FJS: Forgotten Joint Score, CR: cruciate-retaining, BCS: bicruciate-stabilized.
*Statistically significant result.

Table 5. FJS Delta Improvements

Delta improvement	Mean ± SED	*p*-value
CR		
3 mo to 1 yr	9.2 ± 4.6	0.048*
3 mo to 2 yr	16.4 ± 5.1	0.001*
3 mo to 3 yr	34.3 ± 7.6	< 0.001*
BCS		
3 mo to 1 yr	25.3 ± 6.2	< 0.001*
3 mo to 2 yr	32.1 ± 7.1	< 0.001*
3 mo to 3 yr	27.9 ± 7.4	< 0.001*

FJS: Forgotten Joint Score, SED: standard error difference, CR: cruciate-retaining, BCS: bicruciate-stabilized.
*Statistically significant result.

There was no significant difference in the FJS scores between the groups at the 3-month follow-up. However, the BCS cohort experienced a significantly ($p = 0.028$) higher average score 1 year postoperatively compared to the CR cohort (Table 4). Furthermore, the BCS group also showed a significantly greater delta improvement when comparing their 3-month to 1-year postoperative follow-up (Table 4). Both cohorts experienced significant improvements within their respective cohorts when comparing 3 months to 1 year, 2 years, and 3 years after operation (Table 5).

DISCUSSION

This study is novel in that it looked at whether implant design, CR or BCS, had any considerable effects on PROS satisfaction at multiple postoperative time points. We found that design choice did not provide substantial differences as both designs showed similar KOOS, JR improvements from baseline to postoperative scores. In terms of patient satisfaction, the BCS cohort showed a significantly higher average FJS score at 1-year follow-up than the CR cohort; no difference was found between the two cohorts at 2-year and 3-year follow-ups.

In a small cohort study comparing 10 CR and 10 BCS TKAs of the same implant, Moewis et al.[21] reported a general improvement 2 years postoperatively in both cohorts in terms of their Knee Society Scores (KSS), adequate levels of passive knee flexion, and full extension. Furthermore, the BCS cohort showed significantly higher mean KSS scores than the CR cohort. When compared to the KOOS, JR score in our study, the CR cohort showed significantly higher mean KSS scores at the same 2-year postoperative time point. This incongruence between clinical outcome scores and PROS could be due to a small sample size measured exclusively at 2 years postoperatively, whereas our present study noted differences across 12 weeks, 1 year, and 2 years postoperatively. Yet, in agreement with our study, the BCS cohort reported higher FJS scores. The findings of Moewis et al.[21] concur with the present study in that both the CR and BCS cohorts displayed general improvement from their preoperative to postoperative values.

The BCS implant is thought to provide better outcomes and a more natural feeling knee by reproducing native knee physiology.[12,13,21] This is supported by Mugnai et al. who found that patients who received a first-generation model of the BCS implant did experience higher mean KOOS scores at a mean follow-up of 29 months compared to a Non-Restrictive Geometry knee system; however, they were unable to perform a comparison in pre- and postoperative differences due to the lack of preoperative KOOS data.[22] In terms of reproducing the normal kinematics, Inui et al.[23] demonstrated that BCS did have more of a normal-like kinematic than other TKA designs. Elaborating on that, Kiyohara et al.[24] performed an *in vivo* comparison of different TKA implants and found that the BCS designs achieved significantly greater posterior femoral rollback and axial rotation. However, that study did not report clinical outcomes or measures of patient satisfaction. Moewis et al.[21] evaluated patient satisfaction using FJS and found that the BCS cohort also showed higher FJS scores, this was thought to have been contributed by reduced anterior shift and a high lateral rollback. Yet, when the BCS design was compared to a PS design over time, no evidence of clinical superiority was demonstrated at the 2-year follow-up.[25] Ishibashi et al.[26] compared in vivo kinematics and PROS between 17 BCS and 18 CR knees with the same anatomical surface geometry. They found that BCS knees achieved a higher maximum flexion angle, and knee kinematic differences became apparent as patients entered deep knee flexion. Namely, the BCS knees demonstrated rollback in flexion, whereas the CR knees demonstrated paradoxical anterior motion. They hypothesized that posterior impingement may therefore be reducing the maximum flexion angle in CR knees. Despite differences in kinematics, PROS in their analysis did not differ between BCS and CR knees.[26]

While our study compared BCS to CR implants, similarly, the BCS cohort improvements tended to plateau at 2 years postoperatively in congruence with previous findings. A study by Kawakami et al.[27] found no significant differences in PROS or satisfaction among patients who received a CR or PS implant. Furthermore, a large retrospective study comparing CR and PS implant design found that there were no significant postoperative differences in PROS between 3, 5, and 8 years. It was also concluded that there were no significant differences in patient satisfaction when the CR design was compared to the PS design.[28] While our study compared CR and BCS designs, we found that the KOOS, JR score for the CR group was higher for the CR group, yet FJS scores were higher for BCS. This is consistent with the literature that when compared to each other, neither implant demonstrates a clear superiority over the other.

In a large retrospective study on patient satisfaction regarding customized CR implants, Schroeder et al.[29] found high KOOS-JR scores and high patient satisfaction with 89% of their patients reporting to be either satisfied or very satisfied. This agrees with the present study in which patients who received a non-customized CR design reported a higher average KOOS, JR score, with positive trends in patient satisfaction as measured by FJS scores.

While CR implants are linked with excellent patient satisfaction in the literature, there is scarce literature that utilizes FJS specifically. FJS has been previously positively correlated with patient satisfaction.[30] When compared to a PS implant, patients who received a CR implant reported no differences in FJS scores at 1 and 2 years postoperatively.[20] When CR was compared to BCS, BCS displayed a significantly higher FJS score 1 year postoperatively in the present study. Furthermore, BCS displayed higher FJS scores 2 years postoperatively in a previous study reported

by Moewis et al.[21] This is not congruent with our results that showed no significant differences in FJS scores for either CR or BCS at 2 or 3 years postoperatively.

It is important to note that the declining trends for BCS point to a larger issue with patient satisfaction following TKA, which future research should evaluate. The present study also did not look at ensuring the surgeon's selection for CR or BCS. Proper TKA design and constraint must be chosen in order to achieve a favorable outcome as well as long-term satisfaction. Improper implant selection and execution would likely lead to unsatisfactory results. It would also be prudent to consider long-term patient satisfaction in relation to specific implant options throughout the life of said implant as such differences, if there were any, could provide more considerations to surgeons and patients alike.

As this was a retrospective study, there was no randomized selection, thus there was a possible selection bias allocating patients into CR or BCS TKA group. Furthermore, there could have been errors in the data that could not be controlled for. All PRO scores were collected via self-reported survey measures by the patients. Furthermore, preoperative FJS scores are not yet validated, thereby not allowing for a pre- and postoperative comparison as was done with KOOS, JR scores. Additionally, while this study comprises the largest cohort comparing BCS and CR TKA designs, the mean follow-up time of our investigation is limited and future research should look at PROS in long-term follow-up. Nevertheless, the present findings are congruent with the previous literature so this likely did not alter our present conclusions. This study focuses on the differences in PROS exclusively; therefore, complications and revisions were not within the scope of this study.

Contrary to the predicted hypotheses, this study demonstrated that the CR cohort performed better, on average, compared to the BCS cohort in measures of KOOS, JR scores at the latest follow-up. However, the BCS cohort performed better in measures of FJS scores. Another noteworthy finding of this study is that PRO trends for BCS implant recipients decreased in the long-term follow-up, which is in line with previous findings that there is a certain percentage of patients who are dissatisfied with their TKA. Future studies should focus on patient satisfaction following TKA, specifically in the long term. Surgeons should rely on a variety of factors, their experience, and their patients' expectations to determine which implant design is most suitable.

CONFLICT OF INTEREST

RS is a paid consultant for Smith & Nephew and Intellijoint, and has stock options in Intellijoint, Gauss Surgical, and PSI; is a board or committee member for American Academy of Orthopaedic Surgeons and American Association of Hip and Knee Surgeons; editorial or governing board for Arthroplasty Today and Journal of Arthroplasty; intellectual property royalties from Smith & Nephew. JCR is a board or committee member for the New York State Society of Orthopedic Surgeons. MM has stock options in CAIRA surgical, and Constance, paid consultant for Conformis, IP royalties from Innomed, International Society for Technology in Arthroplasty board committee member, and Orthopedics editorial or governing board. No other potential conflicts of interest relevant to this article were reported.

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