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Systematic review

The utility of bicruciate-retaining total knee arthroplasty

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ABSTRACT

Background: We describe the features of modern and historical bicruciate-retaining (BCR) total knee arthroplasty (TKA) implants compared with other TKA implant designs, reviewing kinematics, proprioception, operative technique, and clinical results.

Methods: We performed a review based on PubMed, Embase, CINAHL Plus, and Cochrane databases from January 1990 to April 2016 using combinations of the following keywords: “bicruciate-retaining arthroplasty,” “bicruciate-retaining total knee arthroplasty,” “bicruciate-retaining TKA,” “kinematics,” “knee kinematics,” and “TKA kinematics.”

Results: Four studies have supported the notion that preservation of both cruciate ligaments in TKA preserves more “normal” knee kinematics. BCR implants provide greater proprioceptive performance when compared with posterior cruciate-retaining (CR) TKA implants. However, the operative implantation is more challenging with BCR TKAs, requiring the surgeon to take additional precautions. Overall, there did not seem to be a significant difference in short-term clinical outcomes between the BCR and CR implants.

Conclusions: The utility of BCR TKA is still debatable. The literature has not shown clear indications and guidelines for the value and use of this implant. Although kinematics have been shown to mirror the native knee more closely, the clinical outcomes of BCR vs CR TKAs do not differ significantly. Moreover, additional care must be taken when inserting a BCR implant. The anterior cruciate ligament exploration and preservation is more challenging and certain preparation and precautions must take place. Overall, we have not found that BCR implants are significantly superior to CR implants with regards to short term clinical outcomes despite the BCR TKA having improved kinematics and proprioception.

Introduction and Background

Total knee arthroplasty (TKA) is one of the most effective orthopaedic procedures for pain relief and functional restoration in patients with an arthritic knee. Historically indicated in the elderly population, a demographic shift to the younger more active patient has recently been seen [1]. In conjunction with this change, numerous reports have demonstrated that approximately 20% of patients who undergo TKA procedures are still unsatisfied [2]. This dissatisfaction may potentially be explained by the abnormal kinematics of posterior cruciate-retaining (CR) and cruciate-sacrificing/substituting implant designs, which may affect the muscle moment arms, ligament tension, and proprioceptive instability during knee motion when sacrificing the anterior cruciate ligament (ACL) during TKA [3] (Table 1).

Variations of TKA implants have been designed based on patient demand and activity levels. The different variations include bicruciate-retaining (BCR), posterior CR, posterior-cruciate substituting (CS), and posterior stabilized (PS). BCR TKA is a specialized prosthetic implant that preserves both the ACL and posterior cruciate ligament (PCL). In the CR implant, the ACL is

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Table 1
List of studies reviewed categorized by parameters reviewed.

Studies reviewed	References
Kinematics	[3]
	[4]
	[5]
	[6]
Proprioception	[7]
	[8]
	[9]
	[10]
	[11]
	[12]
	[13]
	[14]
	[15]
	[16]
	[17]
	[18]
Operative technique	[19]
Clinical results	[20]
	[12]
	[21]
	[22]
	[23]

sacrificed, but the PCL is preserved, and the CS and PS implants involve removal of both cruciates. However, the CS implant has a more congruent polyethylene, which adds stability to the joint, whereas the PS implant has a central post that engages the femoral cam to replace the PCL function.

Innovative implants are being developed to simulate the native knee kinematics to potentially improve return to high activity levels, and to allow for better satisfaction. ACL retention may theoretically generate superior proprioception and knee kinematics, thereby improving postoperative function and stability [4]. Theoretically, by lessening the stress transmitted through the prosthesis, BCR TKA has the potential to improve implant longevity.

The literature has not yet provided clear guidelines for the application of BCR TKA implants. In this systematic review, we describe the features of BCR implants compared with other TKA implant designs, review kinematics, proprioception, operative technique, and clinical results.

Material and methods

Twenty-two studies were identified for this systematic review based on electronic searches through the PubMed, Embase, CINAHL Plus, and Cochrane databases from January 1990 to April 2016 using combinations of the following keywords: “bicruciate-retaining arthroplasty,” “bicruciate-retaining total knee arthroplasty,” “bicruciate-retaining TKA,” “kinematics,” “knee kinematics,” and “TKA kinematics.” The inclusion criteria were English language studies that reported on BCR TKA—both cadaveric and actual patient studies focused on implant design features, kinematics, operative techniques, proprioceptive performance, and patient outcomes. The exclusion criteria were studies in other languages, which are not focused on BCR TKA. Each study was reviewed individually by the following authors: SCT, KC, RS for appropriateness. Any disagreements were initially resolved by SCT and KC, until a unified decision about the study design and data was made. All further issues were discussed with the senior author RS for final clarification. Data extraction and assessment were performed by the following authors: FO, SCT, and KC. The data of each study reviewed were extracted for comparison and was not statistically reanalyzed. The parameters we assessed for the BCR TKA included kinematics, proprioception, operative techniques, and clinical outcomes, with each metric being compared with “historical implants” predating the year 2000 and “modern implants” after the year 2000. There are no violations of human or animal rights.

Results

Kinematics

Four studies have supported the notion that preservation of the cruciate ligaments in TKA preserves more “normal” knee kinematics, all using modern implants [3-6]. Stiehl et al [3] performed an in vivo weight-bearing fluoroscopic kinematic analysis reviewing 16 BCR knees (Ceraver Osteal, Paris, France) and comparing them with 6 CR knees (Advantim, Wright Medical Technology, Arlington, TN). The authors reported that in CR TKAs, medial and lateral contact points were significantly posterior at 0 degrees of flexion ($P < .01$, $P < .001$, respectively), and at 60 degrees of flexion, the lateral femoral condyle was significantly posterior ($P < .05$) compared with the bicruciate design. The authors stated that this posterior contact point in extension and posterior translation in deep flexion could potentially lead to increased posterior wear of the polyethylene insert. CR TKAs also demonstrated more anteroposterior translation during the motion arc compared with the BCR TKA, which demonstrated gradual posterior femoral rollback with limited anteroposterior translation. The CR TKA demonstrated abnormal kinematics with anterior translation during flexion. However, limitations of this study include the fact that no other TKA designs were studied such as CS, which has more constraint due to the conforming design, which may have potentially reduced anteroposterior translation. Also, functional activities were not assessed by the authors and this would potentially impact patient satisfaction with one implant design vs the other. Despite these limitations and differences in the kinematics of BCR and CR knees, all patients in this study had similar clinical outcomes at 12-month follow-up.

Similarly, Moro-oka et al [4] compared the kinematic differences between modern BCR and CR knees. More functional activities such as treadmill gait, stair stepping, and maximum flexion activities were assessed in BCR TKA (N2C, Zimmer GmbH, Winterthur, Switzerland) vs CR TKA (Natural-Knee, Zimmer GmbH, Winterthur, Switzerland). Dynamic fluoroscopy and shape matching were used as kinematic assessment tools [4]. Normal knee kinematics were better maintained with BCR as compared with CR knees. In contrast to the Stiehl et al [3] study, the authors in the present study found that CR knees were associated with less anteroposterior translation than BCR knees and that at 72-month follow-up, both TKA designs had similar range of motion (ROM) and Knee Society Scores. The BCR TKA showed greater posterior translation of the lateral femoral condyle than CR knees during kneeling and lunge activities. In addition, the BCR TKA showed greater tibial internal rotation and posterior translations during the maximum flexion activities. Hence, theoretically, BCR knees should have more ROM, but that was not observed at 5 years postoperatively.

Halewood et al [5] investigated the anteroposterior (AP) laxity of a modern BCR implant (Unity Knee, Corin Ltd., Cirencester, UK) to determine whether it was closer to the native knee than a CR implant (Unity Knee, Corin Ltd., Cirencester, UK). The BCR implants did not show a significant difference compared with the native knee, with the difference in AP laxity being 2.5 mm ($P = .039$) [5]. However, CR implants were shown to have significantly greater AP laxity, of 10 mm, than the native knee ($P = .006$) [5]. This was not an uncommon finding, although similar studies concluded the same result [2-5]. Neither prosthesis showed internal/external and valgus/varus rotational laxity differences from the native knee [1]. BCR knees, along with other knee designs also lack the "screw home" mechanism of tibial external rotation with extension, which exists in the native knee.

However, Lo et al [6] examined passive translational and rotational stability properties of the intact knee joint, after a version of a modern bicompartmental knee arthroplasty system, which only replaces the medial and patellofemoral compartments while preserving the ACL and PCL (JOURNEY DEUCE, Smith & Nephew, Memphis, TN) and after modern CR TKA (GENESIS II, Smith & Nephew, Memphis, TN). Knee joint stability after the bicompartmental knee arthroplasty is similar to that of the native knee. The CR TKA results are inferior in joint stability in valgus, varus, external rotation, anterior and, surprisingly in, posterior directions. However, the limitation with cadaveric studies is that it is difficult to simulate functional activities, muscle tension, and weight bearing. Furthermore, each cadaveric specimen is tested several times during the same study in the same sequence (native knee → BCR TKA → CR TKA), and there might be some effect of ligament fatigue that has not been assessed.

Proprioception

In addition to the less natural knee kinematics of a CR implant, sacrificing the ACL may have an impact on knee joint proprioception. Jerosch et al [7] investigated proprioceptive performance of the knee joint with balance testing in 8 conservatively treated patients, 12 surgically treated patients with ACL-deficient knee joints, and 12 healthy control patients. The study concluded that healthy patients had superior knee joint proprioception compared with ACL-deficient knees, and with those who underwent ACL reconstruction.

Fuchs et al [8] evaluated the proprioceptive capabilities of the knee joint after implantation of bicondylar sledge prosthesis (7 Endo, Link, Hamburg, Germany; 8 Search, Aesculap, Tuttlingen, Germany) compared with the contralateral knees and knees of healthy control patients. They reported the proprioceptive properties of the ACL stem from mechanoreceptors. Fifteen patients were evaluated clinically and proprioception was examined using sway measurements during single-leg stance on a force platform. Analysis revealed no significant correlation between clinical scores (Hospital for Special Surgery score, Knee Society score, the patellar score) and sway measurement results. The study concluded that BCR TKA achieves proprioceptive results comparable with healthy subjects of the same age group. It can be inferred that BCR implants provide superior proprioceptive capabilities than CR implants due to preservation of the ACL.

The concern for proprioception begets the question about ACL integrity in the setting of arthritis. ACL integrity was investigated in a study by Ishii et al [9] comparing the percentage of knees with a visually intact ACL before TKA surgery with previously reported values. A total of 247 knees (216 consecutive patients) that underwent TKA were retrospectively evaluated. The preoperative diagnosis for all patients was primary osteoarthritis. The macroscopic appearance of the ACL at the time of surgery was retrospectively assessed using routinely recorded digital photographs and classified as normal, moderately damaged (fissured), or completely ruptured. Both normal and moderately damaged ACLs were defined as intact. Ninety-four percent of the knees (233 of 247) had an intact ACL (normal or moderately damaged). The authors also compare the incidence of an intact ACL described in various studies and report that the incidence varies between 25% and 94% at the time of TKA [9,10,13-15,24]. The results show more potential candidates for BCR TKA than had previously been reported. This suggests that improved techniques for BCR TKA would be clinically useful and could benefit a large number of patients.

Sabouret et al investigated 163 modern BCR Hermes 2C (Ceraver Osteal, Roissy, France) TKAs in 130 patients over 22-year follow-up [16]. Even when the ACL had a partially degenerative appearance, it was preserved as long as the knee had a normal anterior drawer and Lachman test preoperatively. Twelve percent of the knees (20 of 163) in this study were revised because of wear of the polyethylene tibial insert. Excellent stability was achieved and the incidence of aseptic component loosening was 4.3% at 22-year follow-up (7 of 163). The survival rate using revision for any reason as the end point was 82%. The ACL, even when partially degenerated at the time of TKA, remained functional and provided adequate stability at long-term follow-up [16].

However, recent literature has demonstrated that microscopic integrity may be too compromised to make a functional difference postoperatively. Mont et al [17] evaluated the histological condition of the ACL at the time of TKA. Histopathological changes were assessed preoperatively in 173 osteoarthritic knees and graded as absent, mild, moderate, or marked. It was found that degradation, in the form of mucoid degeneration, is commonly seen in 85% of patients, even in visibly intact ligaments. The authors found that combinations of older age, higher body mass index, and greater osteoarthritic changes contributed to a greater degree of histological changes, and may compromise ACL integrity precluding a BCR TKA. Interestingly, in 1996, Simmons et al [18] found that proprioceptive sense is not different between historical unicondylar knee arthroplasty (UKA, Miller-Galante, Zimmer Inc., Warsaw, IN), CR TKA (Miller-Galante II, Zimmer Inc., Warsaw, IN), and CS TKA (Insall-Burstein II, Zimmer Inc., Warsaw, IN) patients. The authors used a proprioception testing device, which consisted of a motor, which rotated the device at a constant angular velocity and an optical encoder that measured angular displacement of the knee in degrees. The patients were blindfolded and subjected to low intensity white noise to control for visual and auditory sensory input. To control for cutaneous sensory input, pneumatic boots were used to secure the lower extremities to the testing apparatus. Subsequently, the patients were then tested for threshold to detect passive motion. The threshold to detection of passive motion was tested from starting positions of 15° knee flexion (near terminal ROM) and 45° knee flexion (mid-ROM). The proprioception testing device moved the knee randomly into flexion or extension at a constant angular velocity from the 2 starting positions. The patient indicated the detection of passive motion by pressing a remote switch. One would imagine that UKA patients would have better proprioception than CR TKA and CS TKA patients based on the presence of the ACL in the UKA group, but that does not seem to be the case in their reported study [18]. Further investigation must be performed to determine whether these results are consistent with modern UKA and CR and CS implants.

Operative technique

In contrast to CR, CS, and PS implants, BCR TKA poses major technical challenges. Technically, the exposure of the ACL and retention of both ligaments and their insertion is more demanding for the arthroplasty surgeon. This additional technical challenge also poses design-related issues such as the absence of a large tibial component keel for fixation and rotational stability. Also, the presence or absence of a metal bridge between the medial and lateral tibial plateaus is a controversial issue that has not been entirely resolved. With the BCR implant, it is essential to ensure ligamentous balancing and avoid abnormal tensioning. The mediolateral positioning of the tibial component must be handled with care to avoid component overhang; joint line restoration to ensure optimal ACL and PCL functionality and knee kinematics; the surgeons must avoid impingement of the femoral component on the central bone block [19].

Clinical results

Although improved kinematics and proprioceptive performance was favored with the BCR TKA, clinical outcomes did not show significant differences when compared with CR TKA. Migaud et al [20] evaluated the influence of posterior tibial slope and ACL sparing on anterior tibial translation in 68 historical BCR Cloutier implants over a mean follow-up period of 5.5 years. They were unable to demonstrate significant differences in ROM, Hospital for Special Surgery knee scores, and functional outcomes between the BCR and CR groups.

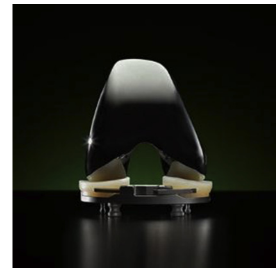
Similarly, Jenny and Jenny [12] investigated the short-term outcomes of 32 historical BCR TKAs (Search Total Knee Prosthesis, Aesculap, Tuttlingen, Germany) compared with 93 historical CR TKAs (Search Total Knee, Aesculap, Tuttlingen, Germany) at 2- to 3-year follow-up period. The authors found that the Knee Society Scores were not significantly different between the 2 groups. They were unable to demonstrate any significant differences in flexion, functional scores, and radiographic outcomes. In this study, there was no advantage in retaining the ACL in a BCR TKA according to short- and midterm outcome analysis. The results of both of these comparative studies may be attributed to the technology that was used in these historical implants.

A comprehensive follow-up study conducted by Cloutier et al [23] investigated 107 historical BCR knees (Hermes 2C; Ceraver Osteal, Roissy, France) for an average of 10 years. The ACL was relatively normal in 96 knees and was partly degenerated in 67 knees. With the use of the Knee Society Score, all 163 knees were prospectively evaluated at yearly intervals; 56 of these knees (in 41 patients) were followed up until the patient died or was lost to follow-up. One hundred four of the 107 knees (97%) available for study at an average of 10 years had an excellent or good result. Pain was adequately relieved in 97 knees (91%) and the average ROM was 107° ± 12.6° (range, 65°-135°). Ninety-five knees (89%) had normal AP stability (less than 5 millimeters of movement in this plane), and 12 knees (11%) had 5-10 millimeters of movement as demonstrated by the drawer sign. The survival rate at 10 years, with revision as the end point, was 95% (±2.0%). The good AP stability in this series after an average follow-up period of 10 years indicates that both the ACL and PCL, even when partly degenerated, remain functional when they are preserved in a TKA. A similar follow-up involving modern implants has yet to be investigated.

However, more positive reports of BCR TKA exist in modern implants. Two hundred fourteen BCR TKAs (Townley Anatomic, BioPro Inc., Port Huron, Michigan) followed for 23 years were examined in a study by Pritchett [22]. The Kaplan-Meier survivorship was 89% at 23 years with revision for any reason as the end point. The mean flexion was 117°, the mean American Knee Society Score improved from the preoperative mean score of 42-91. Twenty-two knees in 21 patients (5.6%) were revised, most commonly because of polyethylene wear. Only 2 patients sustained ACL rupture; one of those patients complained of instability and the second patient had significant polyethylene wear, both necessitating revision surgery. The study concluded that ACL retention provides a stable and well-functioning knee with low likelihood of revision at long-term follow-up.

Pritchett [22] also analyzed patients' preference in their knee implant. Four hundred forty patients underwent staged bilateral TKA using different modern implants on each side. Prostheses used were BCR TKA (BioPro Inc., Port Huron, Michigan and Wright Medical Technology, Arlington, TN), CR TKA (Biomet, Warsaw, IN; BioPro/DePuy; Stryker, Mahwah, NJ; Wright Medical Technology, Arlington, TN; and Zimmer, Warsaw, IN), Medial Pivot (MP) (Wright Medical Technology, Arlington, TN), PS TKA (Biomet/DePuy/Stryker/Wright Medical Technology/Zimmer), and mobile bearing (MB) (DePuy P.F.C. SIGMA) designs. The author reports that the implant selection was randomized and determined from sequential pool based on a table of random numbers. At the 2-year evaluation,

Table 2
Different types of knee implants.

Knee implant designs	
BCR[a]	
CR[b]	
CS[b]	
PS[b]	

[a] Biomet.
[b] Stryker.

the author found that 89.1% of patients preferred the BCR TKA to the PS TKA and 76.2% preferred the MP TKA to the PS TKA. The BCR TKA and the MP TKA were preferred equally. The MP was preferred over the CR design by 76.0%, and 61.4% preferred the MP over the MB design. The PS and CR TKA were preferred equally. ROM, pain relief, alignment and stability did not vary significantly by the prosthesis used. Patients with bilateral TKAs preferred retention of both cruciates with use of the BCR design or substituting with an MP TKA design (Table 2).

Discussion

As previously mentioned, the average age for a TKA patient is shifting to the younger, more active spectrum, which may place increasing demands on surgical technique and TKA implants. A substantial portion of patients continue to remain unhappy with their TKA and hence, it may be important to carefully consider TKA design to attempt a closer recreation of knee kinematics. BCR TKA is an attempt to improve TKA kinematics by preserving the ACL and PCL, with the goal of improving patient satisfaction.

Although there is a recent resurgence in the attention that BCR TKA is receiving, the original prosthesis was developed by Dr. Gunston in the 1960s, who designed the polycentric knee [25]. Thereafter, the 1970s saw several innovations in the design of the BCR TKA in North America, Europe, and Japan [26]. However, most of these designs fell out of favor because of good outcomes associated with other TKA designs such as CR, CS, and PS TKA [1]. Interestingly, clinical outcome studies published recently are largely based on the BCR TKA, designed by Dr. Cloutier in 1975 at St. Luc Hospital in Montreal (Hermes 2C; Ceraver Osteal, Roissy, France) [11].

The aim of this review was to provide the most recent evidence associated with BCR TKA, especially related to restoring knee kinematics, improving proprioception, providing insights into the operative technique, and critically evaluating the clinical outcomes. With regards to knee kinematics, the studies described are able to show that the BCR TKA resembles native knee kinematics to a greater degree than CR TKA. However, the rotational patterns of BCR TKA do not completely resemble those of the native knee, possibly due to the role of the removed menisci [6]. Hence, we must accept the fact that restoring native knee kinematics may not be entirely possible with a TKA prosthesis. Our work had several limitations, first is the current quality of the work available for review, we did not grade the cited studies because of the paucity of work on BCR TKA and the diversity of reported outcomes and measures between the different reports. Second is the large time line we included to collect sufficient literature to review.

Proprioception because of the presence of the ACL mechanoreceptors is also likely preserved in the BCR TKA as compared with ACL-sacrificing designs. However, the ACL integrity is questionable in cases of arthritis, and the impact of macroscopic and microscopic ACL changes on its proprioceptive properties must be examined. Furthermore, regarding operative technique, adequately balancing the ACL and PCL become even more challenging for the arthroplasty surgeon on top of protecting these ligaments while performing the BCR procedure.

The clinical outcomes of historical BCR TKA seem no different from the CR designs, and patients report similar preferences for BCR TKA and MP TKA designs [12,20-23]. However, although there has not been a comprehensive comparison analysis involving modern implants. Hence, there may be more to patient satisfaction and outcomes than preserving the cruciate ligaments and in the future, we may be able to design better prostheses for the younger, more active TKA patient. The only clinical study we found that reported on a modern BCR TKA design (Zimmer Biomet Vanguard XP, Zimmer Biomet, Warsaw, IN) did not show favorable short-term outcomes [27]. At a minimum of 1-year follow-up, the BCR TKA had a higher frequency of all-cause revisions compared with a CR TKA design (5% BCR TKA vs 1.3% CR TKA; hazard ratio [HR], 7.44; 95% confidence interval [CI], 1.24-44.80; $P = .028$). Most of the revisions were for wound-related complications, but other reasons included ACL impingement and aseptic tibial loosening with suspected metal allergy. Modern BCR TKA had a higher frequency of irrigation and debridement compared with modern CR TKA (HR, 0.07; 95% CI, 0.02-0.28; $P < .001$). The proportion of radiolucent lines was greater in the BCR TKA (HR, 2.93; 95% CI, 1.62-5.32; $P < .001$) compared with the CR TKA design. There were no differences between both groups in terms of the Physical Function Computerized Adaptive Test scores, Global10 scores or knee ROM outcomes [27].

Conclusions

The utility of BCR TKA is still debatable. The literature has not shown clear guidelines for the value of this implant and its indications. Although kinematics have been shown to mirror the native knee more closely, the clinical outcomes of BCR vs CR do not yet differ significantly based on newer implant designs, even when comparing historical to modern BCR implants. Moreover, additional care must be taken when inserting a BCR implant. The ACL exploration and preservation is more challenging and certain preparation and precautions must take place. Overall, we have not found that historical or modern BCR implant is significantly superior to CR implants, but future designs may prove differently. In future, more comprehensive studies will be required to learn whether there is truly a clinically significant benefit for the utility of BCR.

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