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## Bicruciate-retaining total knee arthroplasty: What's new?

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### Abstract

Primary total knee arthroplasty (TKA) is a widespread procedure to address end stage osteoarthritis with good results, clinical outcomes, and long-term survivorship. Although it is frequently performed in elderly, an increased demand in young and active people is expected in the next years. However, a considerable dissatisfaction rate has been reported by highly demanding patients due to the intrinsic limitations provided by the TKA. Bicruciate-retaining (BCR) TKA was developed to mimic knee biomechanics, through anterior cruciate ligament preservation. First-generation BCR TKA has not gained popularity due to its being a challenging technique and having poor survival outcomes. Thanks to implant design improvement and surgeon-friendly instrumentation, second-generation BCR TKA has seen renewed interest. This review will focus on surgical indications, kinematical basis, clinical results and latest developments of second-generation BCR TKA.

**Key Words:** Total knee arthroplasty; Anterior cruciate ligament; Bicruciate retaining; Knee kinematics; Second generation design; Knee osteoarthritis treatment

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**Core Tip:** Second-generation bicruciate-retaining total knee arthroplasty (BCR TKA) is designed to overcome the historical durability issues of this implant. Recent kinematics studies point out the advantage of this design in mimicking normal knee motion.

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Second-generation BCR TKA is generally associated with a more restrictive indication range in terms of coronal alignment, anterior cruciate ligament integrity, and preoperative range of motion. Available clinical results demonstrate variable outcomes with short-term follow-up.

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## INTRODUCTION

Primary total knee arthroplasty (TKA) is a widespread surgery, capable of recovering articular function and relieving pain in end-stage osteoarthritis (OA) of the knee[1]. Once considered a procedure for the elderly, primary TKA is nowadays performed frequently in younger and high-demanding patients. Specifically, in the next years, side by side with an overall consistent increase for this procedure demand, the amount of TKA implanted before 65-years-old will exceed 55% of the total procedures[2]. Moreover, along with those demographic variations, despite technical advancement and a 20-year survival rate exceeding 90%, approximately 20% [3] of patients nowadays remain unsatisfied after surgery[4]. Those results are strictly related to the post-operative ability to perform activities of daily life[5]. Clement *et al*[6] have pointed out that those activities are frequently limited by having a TKA, causing a high dissatisfaction rate (25%) mostly in highly demanding patients that consequently see their expectation not fulfilled[7].

This dissatisfaction may potentially be overcome, improving the abnormal kinematics and proprioceptive instability reported by sacrificing the anterior cruciate ligament (ACL) in posterior stabilized (PS) and cruciate-retaining (CR) design[8,9]. Several reports of studies, in fact, mention the role of the ACL in joint kinematics[10], and the paradoxical anterior femoral motion in contemporary design with cruciate sacrifice as cause of dissatisfaction[8,11]. Thus, bicruciate-retaining (BCR) TKA may represent an effective solution to overcome biomechanical concerns and patients' dissatisfaction reported after implant without ACL.

Over the years, previous BCR TKA generations have not gained widespread popularity because of its being a challenging technique and the tension of retained ligaments, the risk for potential instability from ligament failure or tibial island fracture, and inability to correct major deformities of the knee[12]. Moreover, the U-shaped tibial component may lead to component breakage or mobilization because of reduced tibial coverage area and the thin anterior tibial bar[13]. The latest BCR TKA design was developed to overcome those problems. The aim of the literature review performed for this study focuses on surgical indications, results and latest developments about second-generation BCR TKA.

## HISTORICAL NOTES

The first example of cruciate-sparing prosthesis was developed by Gunston[14] in 1960: the "Polycentric Knee". This implant was composed by two semi-circular cemented femoral sliding tracks with two distinct cemented fixed tibial components. Subsequently, the Mayo clinic team created the "Geometric" knee prosthesis, to retain both cruciate, composed of two femoral components linked with a cross-bar and unique polyethylene with a bridge anteriorly to the tibial island[15]. Thanks to Townley[16] in 1972, an anatomic cemented ACL-retaining TKA was created, made of thin, bilobed, horseshoe-shaped femoral components able to limit bone resection and ligaments resection. In 1975, Cloutier *et al*[17,18] developed an anatomic prosthesis with chromium-cobalt femoral component and a U-shaped tibial baseplate with two separated tibial bearing surfaces. The major failure rate on BCR models due to tibial loosening in the early implants, the demanding technique itself and improved clinical outcome of cruciate sacrifice models reduced the interest in development of innovative

design[19]. However, recent studies highlighted the proprioceptive role of the cruciate ligaments, renewing attention in their preservation during knee arthroplasty[20].

In the last years, thanks to advances in technology, saw the introduction of two models of BCR TKA [Vanguard XP Total Knee System (Zimmer Biomet, Warsaw, IN, United States) and Journey II XR (Smith and Nephew plc, Watford, United Kingdom)].

## INDICATIONS

There is a growing interest in performing BCR TKA. As reported by De Faoite *et al*[21] from an international survey, 65% of the interviewed surgeons would consider implanting BCR TKA. Despite this, there is a significant lack of knowledge around patient segmentation for this surgery. Available literature on BCR TKA frequently do not specify indications in a precise manner; moreover, there is a significant overlap between recent unicompartmental (UKA) and bicompartmental knee replacement indications that may be confusing (Table 1). BCR TKA may, in fact, ideally combine the expected advantage of UKA in terms of restoring natural knee kinematics and TKA long-term survival rates. Despite this, the available data make it seem reasonable to choose UKA in case of limited unicompartmental knee OA, in contrast to when at least two compartments are involved in the degenerative process, when the choice between bicompartmental knee replacement and BCR TKA is still unclear. Moreover, age is not a barrier to BCR TKA *per se*[22], but the surgeon should preoperatively and/or intraoperatively evaluate the ACL integrity, the coronal alignment and range of motion (ROM) limitations to decide if this implant is the best choice.

### Coronal alignment

Management of knee malalignment may be challenging in BCR TKA. A preoperative lower-limb alignment evaluation through long-leg radiographs to evaluate the source of deformity is mandatory. Despite this, the literature is unclear and there is considerable debate regarding the influence of preoperative deformity on BCR TKA outcomes[9]. Second-generation BCR TKA is generally associated with a more restrictive indication range[20,23-25]. Bauman *et al*[20], in his comparative study with UKA, excluded varus-valgus deformity of more than 10°, Christensen *et al*[24] included patients with a “minimal coronal deformity”, while Pelt *et al*[25], in his retrospective review of a consecutive series of 175 knees, excluded patients with more than 15° of coronal malalignment. The latter postulate as a possible cause of the low survivorship rate of the BCR TKA reviewed or the pathological variation in knee kinematics that can be introduced with an implant designed to be placed with a traditional mechanical alignment technique within a soft tissue envelope that may not perfectly match after deformity correction. Therefore, exclusion of severe (> 15°) malalignment seems appropriate, but a greater consideration for patient to patient coronal alignment variability and restoration may, with future specifically-designed implants, lead to easier balancing of the ligaments and reduce the tibial component failure rate[26].

### ACL integrity

Integrity assessment of both cruciate ligaments is crucial when a BCR TKA is performed. As recently reported by Ishii *et al*[27], from their retrospective evaluation of 247 TKA, 94% (233/247) of the evaluated knees had a visually intact ACL (normal or moderately damaged) at time of surgery. However, the ACL integrity in terms of strength and proprioception may be questionable in cases of end-stage OA, even though a visually intact ACL is present. Specifically, Mont *et al*[28] evaluated the histological properties of the ACL during TKA in 173 osteoarthritic knees. They reported mucoid degeneration in 85% of patients, even in visually intact ligaments. The authors linked older age, higher body mass index, and greater osteoarthritic changes to the degree of histological changes.

Moreover, as reported by Kawaguchi *et al*[29], this degeneration may extend to both cruciate ligaments, even when the PCL is intact on preoperative evaluation. Therefore, the author suggests to consider posterior stabilized (PS) TKA in case of ACL mucoid degeneration.

In addition, inflammatory arthritis was not considered as exclusion criteria in several clinical studies[13,18,30,31]. This is of special interest because inflammatory arthritis can impact the ACL integrity. More research is required to improve the understanding of inflammatory arthritis and mucoid degeneration role on ACL preserving arthroplasty. Clinical studies, to define ACL integrity, generally rely on

Table 1 Indications and relative contraindications summary

Indications	Relative contraindication
High-demand patients	Low-demand patients
End-stage bi- or tricompartmental knee OA	Severe coronal malalignment ( $> 15^\circ$ )
Coronal malalignment $< 15^\circ$	Inflammatory arthritis
ACL integrity:	ACL mucoid degeneration/absence
Clinical assessment (Lachman, anterior drawer test, pivot shift test)	Relevant preoperative reduction of ROM ( $> 10^\circ$ )
Intraoperative assessment	
Minimal ROM reduction ( $< 5/10^\circ$ )	

ACL: Anterior cruciate ligament; OA: Osteoarthritis; ROM: Range of motion.

visual evaluation[13,18,24,25,31] and/or clinical tests, like Lachmann test, the pivot shift test and anterior drawer test[13,18,25,31-34], while very few use radiological assessment in association. Kono *et al*[35] used a pre-operative magnetic resonance imaging (MRI) to determine the integrity of the ACL, while Pelt *et al*[25] used X-ray signs to indirectly assess the ACL status. In order to understand whether radiology may help in ACL status definition, we may refer to Johnson *et al*[36], who used the Lachman test alone, performed under anaesthesia. The investigators reported the test as ineffective in ACL functional integrity evaluation (33% sensitivity), while combination of the Lachman test with MRI scans brought the sensitivity and specificity of the combined tests to 93.3% and 99% respectively. Despite this, the lines of evidence about the role of MRI imaging or X-ray signs as an indicator of ACL insufficiency are limited. Future research should focus on ACL evaluation to select optimal candidates for this surgery.

### Preoperative ROM

Restoration of a full ROM from a severe preoperative flexion contracture or a limited extension may be challenging in BCR TKA because of the cruciate ligament integrity and consequent confined surgical space, difficult ligament balancing, and soft tissue release.

There is no consensus in the available literature about acceptable preoperative ROM [9]. Christensen *et al*[24] limited their study to “minimal” contracture BCR indication; Pritchett[37] excluded patients with flexion of less than  $90^\circ$  and a flexion contracture of  $20^\circ$  or greater, while Pelt *et al*[25] included patients with less than  $15^\circ$  of flexion contracture.

Lavoie *et al*[34] conducted a retrospective comparative cohort study of 100 BCR TKAs and 100 PS TKAs, focusing on the influence of the preoperative to the postoperative ROM in the two-implant design. They found that BCR TKA with a preoperative flexion contracture equal or superior to  $5^\circ$  were almost 5-times more likely than PS implant to have a flexion contracture post-surgery and 10-times more likely to have a postoperative flexion contracture when the preoperative flexion contracture was equal or greater than  $10^\circ$ . Therefore, despite no systematic analysis being available with regard to the clinical outcomes in literature for second-generation implants, it seems appropriate to initially limit BCR TKA indications to patients with minimal reduction ( $< 10^\circ$ ) in ROM because preoperative motion issues are more likely to persist after TKA if both the cruciate ligaments are preserved.

## TECHNICAL FEATURES

BCR TKA implies major technical challenges and specific complications resulting from ACL retention and difficult tissue balancing. Moreover, this surgery entails specific design-related issues, such as tibial baseplate stability in absence of a large tibial keel for fixation and reduced tibial coverage.

Second-generation implants are designed to overcome those durability issues; this is obtained through tibia component that comes with an asymmetric perimeter shape, a continuous keel and optimized anterior bridge to provide strength, and reduces historical design concerns related to anterior implant fractures to improve tibial

coverage. Furthermore, because some recent studies[24] found that second-generation BCR TKA with a symmetric, non-anatomical design were associated with an higher complication and revision rate. Newer implants are developed with a dedicated anatomical design that approximates physiological joint geometries to better replicate normal knee motion, allowing more mobility in the lateral compartment, as happens in the screw home mechanism, driven by cruciate ligaments. This is obtained through the tibia component, that includes a metal tibia tray with two independent and differently designed medial and lateral inserts with different radius of curvature of the surface and possibility to set different slope in association with an anatomical femoral component with asymmetrical condylar shape.

This new course adopted finds confirmation in the study conducted by Watanabe *et al*[26]. They investigated the effects of several alignment techniques on BCR TKA biomechanics. The most important finding of this study was that a symmetric BCR model implanted with a mechanical alignment demonstrated non-physiological knee biomechanics resulting from over-tensioning of the joint ligaments, especially the PCL and LCL. The rotational alignment of a symmetric femoral component with mechanical alignment (MA) is, in fact, essentially aligned to the epicondylar axis, and consequently the posterior femoral condyle is often larger than that of the preoperative knee and might excessively compress the lateral tibial plateau, resulting in reduced posterior translation of the lateral femoral condyle due to LCL and PCL tightness during knee flexion. Moreover, although the evaluation of a non-anatomical BCR TKA implanted with a kinematic alignment technique demonstrated a significantly reduced ligamentous tension and sensible improvements in joint kinematic, PCL and LCL tensions were still higher when compared to the normal knee. In view of those findings, they concluded that the non-anatomical shape of the evaluated implant contributed to the abnormal kinematic found and considered as a possible solution to those issues related to the introduction of an anatomical BCR TKA.

Therefore, especially in the BCR implant, position of the components must be extremely precise to reach proper ligamentous balancing, avoid femoral component impingement on the central bone island, and restore joint line height and slope to obtain optimal ACL and PCL functionality and knee kinematics.

Despite so, as reported by Peng *et al*[38] in his 3D component orientations analysis relevant variations in component position were observed, especially for the tibial component, using standard instrumentation. Moreover, those variations, especially regarding tibial slope, were related to the 1-year clinical outcomes obtained. Because of this, they concluded that since the BCR TKA design aims to preserve both ACL and PCL it requires a higher level of attention to obtain an accurate and precise component orientation in order to restore the native knee biomechanics. This accuracy may ideally be provided by the use of additional surgical navigation guides/robotic assistance. Despite this, to our knowledge, there are no studies that have investigated the possible advantage of navigation guide or robotic assistance on BCR outcomes.

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## KINEMATIC STUDIES

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Physiological knee kinematics are the result of a harmonic relationship between the articular surface, cruciate and collateral ligaments as well as the surrounding soft tissue. Theoretically, retaining both anterior and posterior cruciate ligament in TKA could contribute to restoration of nearly-normal knee kinematics, maintaining the posterior femoral rollback, reproducing medial pivot rotation and preserving proprioception. However, another aspect to consider that could influence kinematics is the implant design, which has been significantly improved with the last anatomic models. Several *ex vivo* studies demonstrated that BCR implants could preserve the screw-home mechanism, maintaining a more anterior femorotibial contact point, increasing the axial rotation and the posterior displacement through flexion in contrast to the ACL-sacrificing design and similar to a native knee[39-42]. However, in addition to ACL preservation, some authors have highlighted the importance of tibial geometry in the restoration of the physiological knee kinematics[41,43].

In their cadaver kinematic study, Hamada *et al*[43] found that normal rotational kinematics were not reproduced using a second-generation BCR TKA (Vanguard XP Total Knee System (Zimmer Biomet, Warsaw, IN, United States). In the same study, the authors showed that the screw-home mechanism was maintained after meniscectomy and femoral replacement but lost after tibial replacement, emphasizing the role of tibial geometry in implant kinematics[43]. Similarly, Wada *et al*[41], in their kinematic analysis of BCR TKA (Vanguard XP Total Knee System (Zimmer Biomet),



demonstrated that the amount of tibial internal rotation throughout knee flexion was greater, and more similar to the native knee, if a medial constrained insert was used compared to a flat insert. *Ex vivo* investigations on BCR TKA kinematics are partially confirmed by several clinical studies focused on daily activities[44-47]. Arauz *et al*[47] analysed the treadmill walking pattern in 29 patients with unilateral BCR TKA (Vanguard XP Total Knee System (Zimmer Biomet) compared to the non-operated contralateral side, using a combination of computed tomography scan and dual fluoroscopic imaging system[47]. The authors found an asymmetrical gait pattern in their unilateral BCR TKA patients: during the stance phase of gait cycle, a higher flexion and internal tibial rotation were observed in the operated knee; moreover, less anterior/posterior and medial/lateral translation were noticed on the TKA side. Nevertheless, the implanted and non-implanted knee had no significant difference in flexion/extension and axial rotation range of motion. They concluded that knee motion symmetry was not completely restored in patients with unilateral BCR TKA [47].

Hennessy *et al*[45] observed that sex could be an influential factor on knee kinematics in BCR TKA during gait. In their kinematic study, the authors found more antero-posterior interlimb asymmetry (BCR TKA *vs* healthy knee) in female patients (2.8 mm *vs* 1.6 mm) than in male patients (2.3 mm *vs* 1.8 mm) and this finding displayed increased posterior femoral translation throughout most of the stance phases of the gait cycle in female patients[45]. In another study, Arauz *et al*[46] investigated the *in vivo* knee kinematics of unilateral BCR TKA, compared to the healthy side, during daily activities, including sit-to-stand, single-leg deep lunge, and step-up. Performing flexion activities, the BCR TKA side displayed a less posterior contact point on the lateral femoral condyle (from 6° to 100° of flexion). However, the magnitude of the lateral excursion was similar to the non-operated knee, except for the early degree of flexion (0° to 7°). Differently, on the medial side, the extent of femoral translation during knee flexion was inferior and the contact point more variable in BCR TKA compared to the healthy side. In addition, during all the activities, less femoral external rotation during mid-to high flexion was found in the BCR TKA side. The authors concluded that knee kinematics and the screw-home mechanism were only partially replicated with BCR TKA, emphasizing the importance of the implant articular geometry and components positioning[46]. Similar results were obtained in another kinematic study by the same group of authors when investigating strenuous flexion activities in unilateral BCR TKA patients[44].

An interesting *in vivo* biomechanics analysis on cruciate ligament preservation and femoral geometry was provided by Smith *et al*[48]. The authors performed a kinematic evaluation on 50 TKAs with same anatomical femoral geometry (40 Posterior Cruciate Retaining (PCR) - Journey II PCR; 10 BCR TKA - Journey II XR, Smith and Nephew plc, Watford, United Kingdom), during deep knee bending under fluoroscopic surveillance, in comparison to the normal knees (10 subjects). During early flexion, a better restoration of knee kinematics was achieved in BCR TKA subjects compared to PCR TKA, including a more anterior position of both femoral condyles in full extension and more magnitude of posterior-femoral roll back (PFR) in early flexion. However, normal knees showed a more anterior position of the lateral femoral condyle in full extension and more axial rotation compared to both TKA groups. The more posterior contact point of the femoral condyle combined with lesser external rotation shown in BCR TKA was attributed to the differences in femoral geometry between the implant and the native knee. In mid to late flexion, the influence of ACL decreases in favour to PCL, so the differences in kinematics between TKAs become poorer. Nevertheless, the BCR displayed less translational motion compared to PCR, reflecting the importance of balance within ACL and PCL. However, normal knees experienced a continued lateral PFR during flexion, that was only partially achieved in the BCR TKA group[48]. Despite the technical improvement of the second-generation BCR implants, other studies are needed to investigate the biomechanical implications between components design and kinematics.

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## CLINICAL RESULT

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In the literature there are several long-term studies on first-generation BCR TKA, focused on clinical results; all studies have shown a significant improvement in the evaluated scores while ROM assessment indicates varied results (Table 2). Pritchett[31] conducted a longer retrospective study on BCR first-generation implant (Townley Anatomic; Biopro Inc, Port Huron, MI, United States) and reported a significant

**Table 2 Second-generation bicruciate-retaining total knee arthroplasty clinical results**

Ref.	Follow up in mo	BCR model (n)	Pre-op ROM flex, mean	Post-op ROM flex, mean	Pre-op KSS, mean	Post-op KSS, mean	FJS	WOMAC
Alnachoukati <i>et al</i> [23]	12	Vanguard XP (146)	116°	121°	48	96		
Biazzo <i>et al</i> [49]	33.82	Vanguard XP (24)						8.68 (BCR) vs 12.81 (CR)
Baumann <i>et al</i> [20]	18	Vanguard XP (34)					53.4 ± 26.4	
Hennessy <i>et al</i> [45]	12.7	Vanguard XP (29)			58.1 ± 11.8	86.6 ± 16.7		
Kono <i>et al</i> [35]	7.7	Journey II XR	128.7 ± 6.1					
Kalaai <i>et al</i> [33]	3.6	Vanguard XP (61)			36.2 ± 8.1	22 ± 10.1	58.4 ± 33.7	
Peng <i>et al</i> [38]	12.7	Vanguard XP (29)			58.1 ± 11.8	87.9 ± 16.7		
Pelt <i>et al</i> [25]	36	Vanguard XP (141)	121	123				
Tsai <i>et al</i> [32]	12.9	Vanguard XP (30)			58.5	86.6		

BCR: Bicruciate retaining; CR: Cruciate-retaining; FJS: Forgotten joint score; KSS: Knee Society score; ROM: Range of motion; WOMAC: Western Ontario and McMaster Osteoarthritis index

improvement in knee flexion, from a mean pre-operative value of 104° to 117° ( $P = 0.001$ ) and Knee Society Score (KSS) from pre-op mean of 42 to 91 ( $P = 0.001$ ). The same group collected the patients' preferences in bilateral two-stage TKA; four prosthetic design were implanted (bicruciate retaining, posterior cruciate-retaining, medial pivot, and posterior cruciate-substituting). The mean KSS of BCR implants at 8 years follow-up was 92.6, while the mean ROM was 119°. The conclusion of that study was that, despite the mean ROM, neither the pain score, KSS score nor functional score varied significantly between type of knee prosthesis used; patients with bilateral procedures were more likely to prefer retention of their ACL and PCL or substitution with the medial or lateral pivot prosthesis[37]. Lavoie *et al*[34] conducted a retrospective study, in which 100 BCR TKA (Hermes™ 2C ACR) were compared to 100 PS TKA (Hermes PS). They showed a lower post-op KSS in the BCR TKA cohort compared with the PS design (83.9 vs 89.2); moreover, the investigators documented post-operative stiffness at last follow-up in the BCR TKA group (1.5° vs 0.7°,  $P = 0.034$ ). The most important result of the study was the lower maximum passive knee flexion in BCR knees relative to PS knees at every postoperative point, when preoperative flexion was less than 130°.

On the other hand, long-term and comparative studies on second-generation BCR TKA are still not available due to the recent market introduction and few models' availability. Alnachoukati *et al*[23] reported a mean postoperative increase in flexion values (116° preoperative to 121° postoperative) and a mean improvement in terms of KSS (48 to 96). Biazzo *et al*[49] compared functional outcomes between 24 BCR TKA knees [Vanguard XP Total Knee System (Zimmer Biomet)] and 24 CR TKA knees [Vanguard ID Total Knee System (Zimmer Biomet)] in short-term follow up; at the last follow-up, they showed a higher mean Western Ontario and McMaster Osteoarthritis index (WOMAC) score for the BCR group (8.68) than for the CR group (12.81) but no statistically significant difference between the groups ( $P = 0.33$ ). Baumann *et al*[20] demonstrated the superior proprioceptive function of a bicruciate-retaining implant [Vanguard XP Total Knee System (Zimmer Biomet)] compared to unicondylar knee arthroplasty (UKA) and posterior-stabilized TKA (Genesis II Total Knee Replacement System; Smith and Nephew plc, Watford, United Kingdom) at mean follow-up of 18 mo. The BCR group showed no difference in the Forgotten Joint Score (FJS) relative to the UKA group (53.6 ± 22.2 vs 53.4 ± 26.4,  $P = 0.999$ ). The PS TKA group revealed lower mean score value in the FJS compared to the BCR group (38.9 ± 22.3 vs 53.6 ± 22.2,  $P = 0.035$ ) and UKA group ( $P = 0.031$ ).

Hennessy *et al*[45] analysed kinematic gait in females and males (15/14) after BCR TKA implantation [Vanguard XP Total Knee System (Zimmer Biomet)]. The authors

demonstrated significant increases in KSS ( $58.1 \pm 11.8$  preoperative to  $86.6 \pm 16.7$  postoperative,  $P < 0.001$ ). Kalaai *et al*[33] designed a retrospective study in which 61 BCR TKA were compared to 61 CR TKA; the authors observed no statistical differences in FJS score between BCR TKA and CR TKA but a significant improvement ( $P = 0.017$ ) in the EuroQol (EQ-5D) at 3-year follow-up in BCR TKA group. Kono *et al* [35] matched kinematic data from BCR TKA [Journey II XR (Smith and Nephew plc)], UKA and healthy controls during squatting motion, under fluoroscopic surveillance. There was a lower extension angle of UKA knees than healthy and BCR TKA knees ( $P < 0.01$ ), lower flexion angle of BCR TKA knees than healthy and UKA knees ( $P < 0.01$ ), and lower flexion angle of UKA knees than healthy knees ( $P < 0.01$ ). Peng *et al*[38] examined the relation between component alignment and patient reported outcome measures (PROMs) in 29 BCR TKA implants [Vanguard XP Total Knee System (Zimmer Biomet)]. At 1-year follow-up, they verified a significant overall postoperative improvement in KSS ( $8.1 \pm 11.8$  preoperative to  $87.9 \pm 16.7$  postoperative,  $P < 0.001$ ). In that study, the regression analysis demonstrated that the postoperative KSS was negatively associated with a greater posterior tibial slope. Pelt *et al*[25] showed that knee flexion ROM improved from a preoperative mean of  $121^\circ$  to a postoperative mean of  $123^\circ$  after BCR TKA implant. Eventually, Tsai *et al*[32] reported significant improvement from a mean preoperative KSS of 58.5 to a 6-mo postoperative value of 86.6.

## COMPLICATIONS AND REVISION RATES

### First-generation implants

Pritchett[31] presented the largest and longest-term series on first-generation BCR TKA; the author reported on implant of 214 prosthesis (Townley Anatomic) in 160 patients and the clinical outcomes at a minimum follow-up of 20 years. The Kaplan-Meier survivorship was 89% [95% confidence interval (CI): 82%-93%], with revision for any reason as an endpoint. Twenty-two knees in 21 patients (5.6%) were revised and the most common causes were polyethylene wear, aseptic loosening of the femoral or tibial component (seven revisions) and infection (four revisions)[31]. Ries *et al*[50] showed mechanical failure in 20 first-generation BCR TKAs that required revision; the authors retrieved 16 porous coated cementless Ti-6Al-4V tibial trays (BioPro, Port Huron, MI, United States), 2 cast CoCr tibial trays (BioPro), and two all polyethylene tibial implants (Geomedic; Howmedica, Rutherford, NJ, United States). Four failure implant ways were identified, namely fracture of the anterior tibial tray or bridge (fatigue fracture), insert dissociation, UHMWPE wear, and tibial component loosening[21].

### Second-generation implants

Alnachoukati *et al*[23] reported in a short-term review of 146 BCR TKA implantations [Vanguard XP Total Knee System (Zimmer Biomet)], two revisions (1.4% revision rate) due to anterior arthrofibrosis and tibial component subsidence, and 1 reoperation (0.7% reoperation rate) with manipulation under anaesthesia. Nine out of one hundred and forty-six (6.2%) knees had an intraoperative fracture of the tibial island, which occurred in the beginning of the series, fixated with cancellous screw (Table 3).

A match-paired study with a mean follow-up of 33.82 mo carried out by Biazzo *et al* [49] reported two major and two minor complications after implant of 24 BCR TKA [Vanguard XP Total Knee System (Zimmer Biomet)]. There were two aseptic loosening cases with revisions of the tibial component, one periprosthetic joint infection treated conservatively, and one intraoperative fracture of the intercondylar tibial eminence fixed by cortical screw. That study pointed out the increased surgical time in the BCR design [92.19 min standard deviation (SD) 8.56] when compared to the CR design (76.67 min SD 19.91). Early learning curve experiences may explain the longer operative times and the higher complication rate. A case-control study designed by Kalaai *et al*[33] displayed a survival rate of 98.4% for both the CR and BCR TKA groups; one revision in the BCR group was caused by valgus thrust. Klaassen *et al*[51] presented 2 cases (3 knees) of cyclops lesions after BCR TKA with limited knee extension; these were treated by arthroscopic debridement. Therefore, the knee surgeons should suspect this lesion after BCR TKA implantation if full knee extension is not achieved.

Pelt *et al*[25] in their retrospective study on second-generation BCR implants [Vanguard XP Total Knee System (Zimmer Biomet)] revealed a revision-free survival of 88% at mean 3 years follow-up. The main causes of revision were isolated tibial

**Table 3 Second-generation bicruciate-retaining total knee arthroplasty complications**

Ref.	Year	BCR model (n)	Complication	Follow-up time in mo, mean
Alnachoukati <i>et al</i> [23]	2018	Vanguard XP (146)	9 intraoperative tibial island fracture; 1 cyclops lesion; 1 aseptic loosening of tibial component	12
Biazzo <i>et al</i> [49]	2020	Vanguard XP (24)	2 Aseptic loosening; 1 periprosthetic infection; 1 intraoperative tibial island fracture	33.82
Kalaai <i>et al</i> [33]	2019	Vanguard XP (61)	1 valgus thrust	3.6
Klaassen <i>et al</i> [51]	2017	Vanguard XP (3)	2 cyclops lesion (3 knees)	
Pelt <i>et al</i> [25]	2019	Vanguard XP (141)	2 Intraoperative tibial island fracture; 11 arthrofibrosis; 1 hematoma; 1 chronic pain	36

BCR: Bicruciate-retaining.

loosening (5/19), ACL impingement (3/19), chronic pain (3/19), unknown reasons (3/19), femoral and tibial loosening (2/19), metal allergy with chronic pain (1/19), ACL deficiency (1/19), and arthrofibrosis (1/19). There were two intraoperative tibial island fractures that were fixed with a screw[17].

## CONCLUSION

The renewed interest in BCR TKA, as things currently stand, is mainly rooted on component design improvement and biomechanical and kinematical studies that corroborate the possible significant advantage that retention of cruciate ligaments can offer rather than high-quality long-term clinical trials. The literature on first-generation design has showed good long-term survival rates with satisfying clinical outcomes, while the second-generation-based studies have reported heterogeneous results in short to mid-term follow-ups. Anatomical BCR TKA associated with improved patient selection criteria definition for this surgery and greater consideration for patient-to-patient coronal alignment variability and restoration may improve the results obtained thus far. Further high-quality research will be necessary to investigate those hypotheses, evaluate the long-term clinical results, and define the ideal patient for BCR TKA.

## REFERENCES

- 1 **Räsänen P**, Paavolainen P, Sintonen H, Koivisto AM, Blom M, Ryyänen OP, Roine RP. Effectiveness of hip or knee replacement surgery in terms of quality-adjusted life years and costs. *Acta Orthop* 2007; **78**: 108-115 [PMID: 17453401 DOI: 10.1080/17453670610013501]
- 2 **Kurtz SM**, Lau E, Ong K, Zhao K, Kelly M, Bozic KJ. Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030. *Clin Orthop Relat Res* 2009; **467**: 2606-2612 [PMID: 19360453 DOI: 10.1007/s11999-009-0834-6]
- 3 **Gunaratne R**, Pratt DN, Banda J, Fick DP, Khan RJK, Robertson BW. Patient Dissatisfaction Following Total Knee Arthroplasty: A Systematic Review of the Literature. *J Arthroplasty* 2017; **32**: 3854-3860 [PMID: 28844632 DOI: 10.1016/j.arth.2017.07.021]
- 4 **Bourne RB**, Chesworth BM, Davis AM, Mahomed NN, Charron KD. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? *Clin Orthop Relat Res* 2010; **468**: 57-63 [PMID: 19844772 DOI: 10.1007/s11999-009-1119-9]
- 5 **Nakahara H**, Okazaki K, Mizu-Uchi H, Hamai S, Tashiro Y, Matsuda S, Iwamoto Y. Correlations between patient satisfaction and ability to perform daily activities after total knee arthroplasty: why aren't patients satisfied? *J Orthop Sci* 2015; **20**: 87-92 [PMID: 25366699 DOI: 10.1007/s00776-014-0671-7]
- 6 **Clement ND**, MacDonald D, Patton JT, Burnett R. Post-operative Oxford knee score can be used to indicate whether patient expectations have been achieved after primary total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2015; **23**: 1578-1590 [PMID: 24488224 DOI: 10.1007/s00167-014-2865-0]
- 7 **Nakano N**, Shoman H, Olavarria F, Matsumoto T, Kuroda R, Khanduja V. Why are patients dissatisfied following a total knee replacement? *Int Orthop* 2020; **44**: 1971-2007 [PMID: 32642827]

- DOI: [10.1007/s00264-020-04607-9](https://doi.org/10.1007/s00264-020-04607-9)]
- 8 **Komistek RD**, Allain J, Anderson DT, Dennis DA, Goutallier D. In vivo kinematics for subjects with and without an anterior cruciate ligament. *Clin Orthop Relat Res* 2002; 315-325 [PMID: [12439275](https://pubmed.ncbi.nlm.nih.gov/12439275/) DOI: [10.1097/00003086-200211000-00047](https://doi.org/10.1097/00003086-200211000-00047)]
  - 9 **Boese CK**, Ebohon S, Ries C, De Faoite D. Bi-cruciate retaining total knee arthroplasty: a systematic literature review of clinical outcomes. *Arch Orthop Trauma Surg* 2021; **141**: 293-304 [PMID: [33047230](https://pubmed.ncbi.nlm.nih.gov/33047230/) DOI: [10.1007/s00402-020-03622-0](https://doi.org/10.1007/s00402-020-03622-0)]
  - 10 **Shabani B**, Bytyqi D, Lustig S, Cheze L, Bytyqi C, Neyret P. Gait changes of the ACL-deficient knee 3D kinematic assessment. *Knee Surg Sports Traumatol Arthrosc* 2015; **23**: 3259-3265 [PMID: [25026934](https://pubmed.ncbi.nlm.nih.gov/25026934/) DOI: [10.1007/s00167-014-3169-0](https://doi.org/10.1007/s00167-014-3169-0)]
  - 11 **Dennis DA**, Komistek RD, Colwell CE Jr, Ranawat CS, Scott RD, Thornhill TS, Lapp MA. In vivo anteroposterior femorotibial translation of total knee arthroplasty: a multicenter analysis. *Clin Orthop Relat Res* 1998; 47-57 [PMID: [9917667](https://pubmed.ncbi.nlm.nih.gov/9917667/) DOI: [10.1016/s0883-5403\(98\)90133-4](https://doi.org/10.1016/s0883-5403(98)90133-4)]
  - 12 **Cherian JJ**, Kapadia BH, Banerjee S, Jauregui JJ, Harwin SF, Mont MA. Bicruciate-retaining total knee arthroplasty: a review. *J Knee Surg* 2014; **27**: 199-205 [PMID: [24764232](https://pubmed.ncbi.nlm.nih.gov/24764232/) DOI: [10.1055/s-0034-1374812](https://doi.org/10.1055/s-0034-1374812)]
  - 13 **Sabouret P**, Lavoie F, Cloutier JM. Total knee replacement with retention of both cruciate ligaments: a 22-year follow-up study. *Bone Joint J* 2013; **95-B**: 917-922 [PMID: [23814243](https://pubmed.ncbi.nlm.nih.gov/23814243/) DOI: [10.1302/0301-620X.95B7.30904](https://doi.org/10.1302/0301-620X.95B7.30904)]
  - 14 **Gunston FH**. Polycentric knee arthroplasty. Prosthetic simulation of normal knee movement. *J Bone Joint Surg Br* 1971; **53**: 272-277 [PMID: [5578223](https://pubmed.ncbi.nlm.nih.gov/5578223/)]
  - 15 **Cracchiolo A 3rd**, Benson M, Finerman GA, Horacek K, Amstutz HC. A prospective comparative clinical analysis of the first-generation knee replacements: polycentric vs. geometric knee arthroplasty. *Clin Orthop Relat Res* 1979; 37-46 [PMID: [535288](https://pubmed.ncbi.nlm.nih.gov/535288/)]
  - 16 **Townley CO**. The anatomic total knee resurfacing arthroplasty. *Clin Orthop Relat Res* 1985; 82-96 [PMID: [3967443](https://pubmed.ncbi.nlm.nih.gov/3967443/)]
  - 17 **Cloutier JM**. Results of total knee arthroplasty with a non-constrained prosthesis. *J Bone Joint Surg Am* 1983; **65**: 906-919 [PMID: [6885871](https://pubmed.ncbi.nlm.nih.gov/6885871/)]
  - 18 **Cloutier JM**, Sabouret P, Deghrar A. Total knee arthroplasty with retention of both cruciate ligaments. A nine to eleven-year follow-up study. *J Bone Joint Surg Am* 1999; **81**: 697-702 [PMID: [10360698](https://pubmed.ncbi.nlm.nih.gov/10360698/) DOI: [10.2106/00004623-199905000-00011](https://doi.org/10.2106/00004623-199905000-00011)]
  - 19 **Jenny JY**, Jenny G. Preservation of anterior cruciate ligament in total knee arthroplasty. *Arch Orthop Trauma Surg* 1998; **118**: 145-148 [PMID: [9932189](https://pubmed.ncbi.nlm.nih.gov/9932189/) DOI: [10.1007/s004020050335](https://doi.org/10.1007/s004020050335)]
  - 20 **Baumann F**, Bahadin Ö, Krutsch W, Zellner J, Nerlich M, Angele P, Tibesku CO. Proprioception after bicruciate-retaining total knee arthroplasty is comparable to unicompartmental knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2017; **25**: 1697-1704 [PMID: [27145774](https://pubmed.ncbi.nlm.nih.gov/27145774/) DOI: [10.1007/s00167-016-4121-2](https://doi.org/10.1007/s00167-016-4121-2)]
  - 21 **De Faoite D**, Ries C, Foster M, Boese CK. Indications for bi-cruciate retaining total knee replacement: An international survey of 346 knee surgeons. *PLoS One* 2020; **15**: e0234616 [PMID: [32542002](https://pubmed.ncbi.nlm.nih.gov/32542002/) DOI: [10.1371/journal.pone.0234616](https://doi.org/10.1371/journal.pone.0234616)]
  - 22 **Rivière C**, Vendittoli PA, editors. Personalized Hip and Knee Joint Replacement [Internet]. Cham (CH): Springer; 2020 [PMID: [33347098](https://pubmed.ncbi.nlm.nih.gov/33347098/) DOI: [10.1007/978-3-030-24243-5](https://doi.org/10.1007/978-3-030-24243-5)]
  - 23 **Alnachoukati OK**, Emerson RH, Diaz E, Ruchaud E, Ennin KA. Modern Day Bicruciate-Retaining Total Knee Arthroplasty: A Short-Term Review of 146 Knees. *J Arthroplasty* 2018; **33**: 2485-2490 [PMID: [29666029](https://pubmed.ncbi.nlm.nih.gov/29666029/) DOI: [10.1016/j.arth.2018.03.026](https://doi.org/10.1016/j.arth.2018.03.026)]
  - 24 **Christensen JC**, Brothers J, Stoddard GJ, Anderson MB, Pelt CE, Gililland JM, Peters CL. Higher Frequency of Reoperation With a New Bicruciate-retaining Total Knee Arthroplasty. *Clin Orthop Relat Res* 2017; **475**: 62-69 [PMID: [27043727](https://pubmed.ncbi.nlm.nih.gov/27043727/) DOI: [10.1007/s11999-016-4812-5](https://doi.org/10.1007/s11999-016-4812-5)]
  - 25 **Pelt CE**, Sandifer PA, Gililland JM, Anderson MB, Peters CL. Mean Three-Year Survivorship of a New Bicruciate-Retaining Total Knee Arthroplasty: Are Revisions Still Higher Than Expected? *J Arthroplasty* 2019; **34**: 1957-1962 [PMID: [31160154](https://pubmed.ncbi.nlm.nih.gov/31160154/) DOI: [10.1016/j.arth.2019.04.030](https://doi.org/10.1016/j.arth.2019.04.030)]
  - 26 **Watanabe M**, Kuriyama S, Nakamura S, Nishitani K, Tanaka Y, Sekiguchi K, Ito H, Matsuda S. Abnormal knee kinematics caused by mechanical alignment in symmetric bicruciate-retaining total knee arthroplasty are alleviated by kinematic alignment. *Knee* 2020; **27**: 1385-1395 [PMID: [33010752](https://pubmed.ncbi.nlm.nih.gov/33010752/) DOI: [10.1016/j.knee.2020.07.099](https://doi.org/10.1016/j.knee.2020.07.099)]
  - 27 **Ishii Y**, Noguchi H, Sato J, Yamamoto T, Takayama S, Toyabe S. Macroscopic evaluation of the anterior cruciate ligament in osteoarthritic patients undergoing total knee arthroplasty. *Eur J Orthop Surg Traumatol* 2016; **26**: 205-208 [PMID: [26718564](https://pubmed.ncbi.nlm.nih.gov/26718564/) DOI: [10.1007/s00590-015-1736-9](https://doi.org/10.1007/s00590-015-1736-9)]
  - 28 **Mont MA**, Elmallah RK, Cherian JJ, Banerjee S, Kapadia BH. Histopathological Evaluation of the Anterior Cruciate Ligament in Patients Undergoing Primary Total Knee Arthroplasty. *J Arthroplasty* 2016; **31**: 284-289 [PMID: [26239235](https://pubmed.ncbi.nlm.nih.gov/26239235/) DOI: [10.1016/j.arth.2015.07.010](https://doi.org/10.1016/j.arth.2015.07.010)]
  - 29 **Kawaguchi K**, Michishita K, Manabe T, Akasaka Y, Arakawa T, Higuchi J. Mucoïd degeneration of the cruciate ligaments in osteoarthritis under primary total knee arthroplasty. *Asia Pac J Sports Med Arthrosc Rehabil Technol* 2018; **12**: 1-4 [PMID: [29963370](https://pubmed.ncbi.nlm.nih.gov/29963370/) DOI: [10.1016/j.asmart.2017.12.002](https://doi.org/10.1016/j.asmart.2017.12.002)]
  - 30 **Cloutier JM**. Long-term results after nonconstrained total knee arthroplasty. *Clin Orthop Relat Res* 1991; 63-65 [PMID: [1959288](https://pubmed.ncbi.nlm.nih.gov/1959288/)]
  - 31 **Pritchett JW**. Bicruciate-retaining Total Knee Replacement Provides Satisfactory Function and Implant Survivorship at 23 Years. *Clin Orthop Relat Res* 2015; **473**: 2327-2333 [PMID: [25721577](https://pubmed.ncbi.nlm.nih.gov/25721577/) DOI: [10.1007/s11999-015-4219-8](https://doi.org/10.1007/s11999-015-4219-8)]

- 32 **Tsai TY**, Liow MHL, Li G, Arauz P, Peng Y, Klemt C, Kwon YM. Bi-Cruciate Retaining Total Knee Arthroplasty Does Not Restore Native Tibiofemoral Articular Contact Kinematics During Gait. *J Orthop Res* 2019; **37**: 1929-1937 [PMID: [31062398](#) DOI: [10.1002/jor.24333](#)]
- 33 **Kalaai S**, Scholtes M, Borghans R, Boonen B, van Haaren E, Schotanus M. Comparable level of joint awareness between the bi-cruciate and cruciate retaining total knee arthroplasty with patient-specific instruments: a case-controlled study. *Knee Surg Sports Traumatol Arthrosc* 2020; **28**: 1835-1841 [PMID: [31286164](#) DOI: [10.1007/s00167-019-05613-0](#)]
- 34 **Lavoie F**, Al-Shakfa F, Moore JR, Mychaltchouk L, Iguer K. Postoperative Stiffening after Bicruciate-Retaining Total Knee Arthroplasty. *J Knee Surg* 2018; **31**: 453-458 [PMID: [28738430](#) DOI: [10.1055/s-0037-1604145](#)]
- 35 **Kono K**, Inui H, Tomita T, Yamazaki T, Taketomi S, Tanaka S. Bicruciate-retaining total knee arthroplasty reproduces *in vivo* kinematics of normal knees to a lower extent than unicompartmental knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2020; **28**: 3007-3015 [PMID: [31641811](#) DOI: [10.1007/s00167-019-05754-2](#)]
- 36 **Johnson AJ**, Howell SM, Costa CR, Mont MA. The ACL in the arthritic knee: how often is it present and can preoperative tests predict its presence? *Clin Orthop Relat Res* 2013; **471**: 181-188 [PMID: [22864617](#) DOI: [10.1007/s11999-012-2505-2](#)]
- 37 **Pritchett JW**. Patient preferences in knee prostheses. *J Bone Joint Surg Br* 2004; **86**: 979-982 [PMID: [15446522](#) DOI: [10.1302/0301-620X.86B7.14991](#)]
- 38 **Peng Y**, Arauz P, An S, Limmahakhun S, Klemt C, Kwon YM. Does Component Alignment Affect Patient Reported Outcomes following Bicruciate Retaining Total Knee Arthroplasty? *J Knee Surg* 2020; **33**: 798-803 [PMID: [31064018](#) DOI: [10.1055/s-0039-1688500](#)]
- 39 **Heyse TJ**, Slane J, Peersman G, Dirckx M, van de Vyver A, Dworschak P, Fuchs-Winkelmann S, Scheys L. Kinematics of a bicruciate-retaining total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2017; **25**: 1784-1791 [PMID: [28078394](#) DOI: [10.1007/s00167-016-4414-5](#)]
- 40 **Koh YG**, Son J, Kwon SK, Kim HJ, Kwon OR, Kang KT. Preservation of kinematics with posterior cruciate-, bicruciate- and patient-specific bicruciate-retaining prostheses in total knee arthroplasty by using computational simulation with normal knee model. *Bone Joint Res* 2017; **6**: 557-565 [PMID: [28947604](#) DOI: [10.1302/2046-3758.69.BJR-2016-0250.R1](#)]
- 41 **Wada K**, Hamada D, Takasago T, Nitta A, Goto T, Tonogai I, Tsuruo Y, Sairyō K. The medial constrained insert restores native knee rotational kinematics after bicruciate-retaining total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2019; **27**: 1621-1627 [PMID: [30382288](#) DOI: [10.1007/s00167-018-5249-z](#)]
- 42 **Peersman G**, Slane J, Dirckx M, Vandevyver A, Dworschak P, Heyse TJ, Scheys L. The influence of polyethylene bearing thickness on the tibiofemoral kinematics of a bicruciate retaining total knee arthroplasty. *Knee* 2017; **24**: 751-760 [PMID: [28433348](#) DOI: [10.1016/j.knee.2017.03.010](#)]
- 43 **Hamada D**, Wada K, Takasago T, Goto T, Nitta A, Higashino K, Fukui Y, Sairyō K. Native rotational knee kinematics are lost in bicruciate-retaining total knee arthroplasty when the tibial component is replaced. *Knee Surg Sports Traumatol Arthrosc* 2018; **26**: 3249-3256 [PMID: [29368122](#) DOI: [10.1007/s00167-018-4842-5](#)]
- 44 **Kwon YM**, Arauz P, Peng Y, Klemt C. In vivo kinematics of deep lunges and sit-to-stand activities in patients with bicruciate-retaining total knee arthroplasty. *Bone Joint J* 2020; **102-B**: 59-65 [PMID: [32475273](#) DOI: [10.1302/0301-620X.102B6.BJJ-2019-1552.R2](#)]
- 45 **Hennessy D**, Arauz P, Klemt C, An S, Kwon YM. Gender Influences Gait Asymmetry following Bicruciate-Retaining Total Knee Arthroplasty. *J Knee Surg* 2020; **33**: 582-588 [PMID: [30861536](#) DOI: [10.1055/s-0039-1681092](#)]
- 46 **Arauz P**, Klemt C, Limmahakhun S, An S, Kwon YM. Stair Climbing and High Knee Flexion Activities in Bi-Cruciate Retaining Total Knee Arthroplasty: In Vivo Kinematics and Articular Contact Analysis. *J Arthroplasty* 2019; **34**: 570-576 [PMID: [30514641](#) DOI: [10.1016/j.arth.2018.11.013](#)]
- 47 **Arauz P**, Peng Y, Kwon YM. Knee motion symmetry was not restored in patients with unilateral bi-cruciate retaining total knee arthroplasty-in vivo three-dimensional kinematic analysis. *Int Orthop* 2018; **42**: 2817-2823 [PMID: [29779140](#) DOI: [10.1007/s00264-018-3986-8](#)]
- 48 **Smith LA**, Nachtrab J, LaCour M, Cates H, Freeman MG, Komistek RD. In Vivo Knee Kinematics: How Important Are the Roles of Femoral Geometry and the Cruciate Ligaments? *J Arthroplasty* 2021; **36**: 1445-1454 [PMID: [33214016](#) DOI: [10.1016/j.arth.2020.10.020](#)]
- 49 **Biazzo A**, D'Ambrosi R, Staals E, Masia F, Izzo V, Verde F. Early results with a bicruciate-retaining total knee arthroplasty: a match-paired study. *Eur J Orthop Surg Traumatol* 2021; **31**: 785-790 [PMID: [33215307](#) DOI: [10.1007/s00590-020-02834-9](#)]
- 50 **Ries MD**, Lenz N, Jerry G, Salehi A, Haddock S. Is modern bicruciate retaining TKA feasible? *Semin Arthroplasty* 2018; **29**: 55-57 [DOI: [10.1053/j.sart.2018.04.012](#)]
- 51 **Klaassen MA**, Aikins JL. The cyclops lesion after bicruciate-retaining total knee replacement. *Arthroplast Today* 2017; **3**: 242-246 [PMID: [29204489](#) DOI: [10.1016/j.artd.2017.06.002](#)]



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