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Bicruciate retaining total knee arthroplasty: current state and future promise

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Total knee arthroplasty (TKA) is a well-known surgical procedure performed to address end stage osteoarthritis. The main goal is to relieve pain, recover articular function and return to normal function as soon as possible. Over the years it is frequently performed in the elderly, but lately there is an increased demand in a younger and more active population. Up to 25% of patients feel dissatisfied about their TKA. The anterior cruciate ligament (ACL) is considered the main anteroposterior stabilizer of the knee; nevertheless the ACL is usually sacrificed during conventional TKA. Research shows this might be an unnecessary sacrifice in certain cases. The considerable dissatisfaction rate in mainly high-demanding patients, together with the literature reports on the importance of the ACL function, were the two main reasons for the development of bicruciate retaining (BCR) total knee arthroplasty. BCR TKA may offer superior knee kinematics and proprioception, through anterior cruciate ligament preservation, but requires a higher level of attention to obtain an accurate and precise component orientation to reach proper ligamentous balancing and restore the native knee biomechanics. Many surgeons abandoned its use due to its challenging technique and inconsistent results. Recent new BCR implant designs are promising. This systematic literature review aims to summarize the current state of BCR TKA and what to expect in the future.

Key words: bicruciate retaining, total knee arthroplasty, total knee replacement.

INTRODUCTION

Joint replacement procedures with total knee arthroplasty are growing globally. The first mention of any type of TKA in literature was in the late 1800s. It all started with resection and interposition arthroplasty. This was followed in the next century by the first hemi-arthroplasty in the 1940s. The new era of TKA began with the introduction of the hinged knee prosthesis in the 1950s. The implants developed in the 1970s offered a foundation for the concepts and technologies used today[1]. Historically TKA was mainly performed in the elderly; over the last decade we see a significant shift to the more young and active patients with higher functional demands[2]. In the next years, the amount of TKA implanted before 65-years-old will exceed 55% of the total procedures. Despite technical advancement and a 20-year survival rate exceeding 90%, we still face difficulties[3]. Numerous articles have reported a dissatisfaction of up to 20-25% amongst patients who underwent TKA[1]. Possible reasons for dissatisfaction are altered kinematics, including paradoxical anterior femoral translation and reduced proprioception after TKA[2,4,5]. Literature shows the important anteroposterior stabilizing role of the ACL in optimal knee kinematics and proprioception[6,7]. Sacrificing the ACL during TKA therefore seems wrong, at least on a biomechanical point of view. Studies show that the ACL is still present in up to 60-80% of arthritic knees[1,6]. Ishii et al. evaluated the ACL at time of surgery in a retrospective study of 247 TKA and reported a visually intact ACL (normal or moderately damaged) in 94%[8]. However, the ACL integrity in terms of strength and proprioception may be questionable in cases of end-stage osteoarthritis. On evaluating the histological properties of the ACL during TKA in 173 osteoarthritic knees, they (Mont et al.) reported mucoid degeneration in 85% of patients, even in visually intact ligaments[3].

Unicompartmenal knee arthroplasty (UKA) is a widely recognized treatment for isolated compartment osteoarthritis of the knee[9]. Depending on the implant design, a functioning ACL is required. The usage of medial UKA depends on the integrity of the lateral compartment cartilage. If the lateral compartment is damaged, conversion to TKA is performed in

most cases, even with an intact ACL[10]. Another potentially useful option in case of bicompartmental femorotibial osteoarthritis (medial and lateral) is bi-unicompartimental knee arthroplasty (bi-UKA), where both compartments can be resurfaced individually[10]. In the early literature, bi-UKA was performed for very severe osteoarthritis and rheumatoid arthritis, but indications have evolved over time. Both mobile and fixed bearing implants have been used; with the latter being the most frequent choice[9]. Operating both medial and lateral compartment at the same time is referred to as "simultaneous" bi-UKA, opposed to "staged" bi-UKA in which a lateral or medial UKA is added, due to progression of contralateral femorotibial osteoarthritis to a knee with an existing, good-functioning UKA. The Wada et al. review indicates bi-UKA is a feasible and viable surgical option with good functional outcomes of both simultaneous and staged bi-UKA for bicompartmental femorotibial osteoarthritis in carefully selected patients. However, the data on long-term follow-up studies and outcomes remains limited[9]. When bi-UKA and TKA are compared for the treatment of medial and lateral knee osteoarthritis, bi-UKA is favorable in some clinical rating systems (e.g., the Knee Society Score, Stiffness indexes), but there is no statistical significant difference. Moreover, similar postoperative hip-knee-ankle angles can be expected 3 years after bi-UKA and TKA[11,12]. Confalonieri et al. published a 48 months follow-up study comparing bi-UKA versus TKA in a matched paired study, concluding bi-UKA is a viable option for bicompartmental femorotibal osteoarthritis at least as well as TKA, but maintaining a higher level of function[11].

Bicruciate retaining TKA implants preserve both the anterior and the posterior cruciate ligament, hence considered to be offering superior knee kinematics and proprioception. BCR TKA is a possible alternative to conventional TKA, but it is a technically demanding procedure and the results are not always consistent[10]. The BCR implant design was already developed in the early stages of TKA. Retention of the ACL was secured with horseshoe designs of the tibia component. Dr. Gunston introduced the first BCR prosthesis in the middle 1960s, aiming at preservation of normal biomechanics[13]. Many surgeons abandoned its use due to its challenging technique and inconsistent survival outcomes. If the alleged advantages of BCR TKA are indeed true, why aren't we all using it today?

METHODS

This systematic literature review aims to summarize the current state of BCR TKA and what to expect in the future. Following the PRISMA guidelines (Preferred Items for Systematic Reviews and Meta-Analyses), we performed a search for articles on the electronic databases of Pubmed, Google Scholar and Embase. Several search methods were used. The first author (AC) performed the search for articles, while the other reviewers (NA, JV) supervised the search method. We used the following keywords and MeSH terms: "bicruciate retaining", "bi-cruciate retaining", "total knee arthroplasty" and "total knee replacement". We started by reading multiple articles on the subject to get a global image of the current knowledge of BCR TKA. We collected a big sample of articles. On reading we made a selection based on inclusion and exclusion criteria. As inclusion criteria we used the following: publication after 2008 (15 years), impact factor of the journal, free full text available, objectivity of the reviewers, no conflict of interest bias. We excluded articles that were not written in English. Finally we screened the references of the articles for additional publications that were not previously found and also met our selection criteria. Based on these criteria a selection was made of 17 adequate and relevant articles.

RESULTS

Available literature on BCR TKA frequently do not specify indications in a precise manner, more-over there is a significant overlap between recent uni-compartmental and bicompartmental knee replacement indications that may be confusing. The available data make it seem reasonable to choose for unicompartmental knee replacement in case of limited unicompartmental knee osteoarthritis. In contrast, the choice between bicompartmental knee replacement and BCR TKA, when at least two compartments are involved in the degenerative process, remains unclear[3]. Mucoid degeneration of the ACL may extend to both cruciate ligaments, even when the PCL is intact in preoperative evaluation[8]. Therefore Kawaguchi et al. suggest considering posterior stabilized (PS) TKA in case of mucoid degeneration of the ACL[14]. Several clinical studies did not consider inflammatory arthritis as exclusion criteria even though it can have an enormous impact on the ACL integrity[14]. Based on fifteen publications, Boese et al. reported several indications and limitations for BCR TKA implantation[2]. General indications based on etiology are the following: osteoarthritis, rheumatoid (inflammatory) arthritis, osteonecrosis and post-traumatic degeneration. Another important indication was varus and valgus deformity before surgery. In valgus deformity a strict limitation

was varying between 10° and 20°. Varus deformities were accepted of up tot 30°. One report even accepted valgus deformity of 30°. At last they mention flexion contractures, where some indications were limited to "minimal" contracture, wile others did not restrict indications and reported surgery in cases with 25-65° of flexion contracture. Second generation implants were associated with more restrictive indication spectrum, though no exact reports could be found[2]. Da Faoite et al. also published a report on indications for BCR TKA in 2020 indicating that pre-existing inflammatory arthritis, age over 80 years, body mass index above 34,9kg/m^2, a varus or valgus deformity of more than 10°, and flexion contractures of more than 10° should be considered relative contraindications for BCR TKA. BCR TKA experienced surgeons are less restrictive[15]. Chu-Man Lau et al. remarks that these recommendations do not consider quadriceps weakness, possibly due to generalized sarcopenia, as a mitigating factor for BCR TKA. Quadriceps muscle weakness may have an important contribution to complications after BCR TKA such as periprosthetic fractures[16].

Anteroposterior (AP) laxity of the knee joint is restored in bicruciate retaining TKA[6,17]. Arnout et al. tested the knee joint laxity with and without external loads on fourteen cadaveric specimens. Subsequently the native knee, bicruciate retaining (BCR), cruciate retaining (CR) and finally bicruciate substituting (BCS) total knee arthroplasty were tested. They concluded that the laxity pattern of the bicruciate retaining knee was best approximated by that of the native knee under passive conditions. Important to notice is that the effect of muscle activation is known to significantly alter stability and kinematics. Their results also showed that posterior cruciate retaining designs and bicruciate substituting designs reduce the laxity envelope and therefore lead to a stiffer knee[17].

Halewood et al. performed a biomechanical cadaver study to evaluate the laxity after BCR TKA hypothesizing that the kinematics with the BCR TKA would be closer to those of the native knee than the posterior cruciate retaining TKA, particularly in the anteroposterior direction. The BCR TKA demonstrated anterior drawer laxity, total AP laxity and neutral range of motion significantly closer to the native knee than the CR TKA. The BCR TKA concept was shown to be a valid approach to reducing AP laxity in the knee compared to CR TKA[6].

Pritchett conducted a randomized, prospective study on 440 patients who underwent bilateral, staged primary total knee arthroplasty from June 1987 until September 2005, using different prosthesis on each side. The goal of this study was to find the preference of the patient. This preference was based on the following reasons: feels more normal, stronger on stairs, superior single-leg weight bearing, flexion stability, feels more stable overall, fewer clunks/pops/clicks and sometimes for no reason at all. He used 5 types of knee prosthesis, one of which was the BCR prosthesis. He excluded patients with fair or poor results in one or both knees to avoid comparing a fair or poor result to a good or excellent result. All the patients in his report, therefore, had a good or excellent result in both knees with different prosthesis. The conclusion of this study stated that patients who underwent bilateral staged total knee arthroplasty were more likely to prefer retention of their ACL and PCL (BCR TKA) or the medial pivot prosthesis over the conventional posterior cruciate retaining and posterior substituting or mobile bearing knee[18].

The report by Christensen et al., comparing the BCR to CR TKA, failed to demonstrate any differences in patient-reported outcomes between the two groups. Older studies have primarily focused on implant survivorship and surgeon-reported outcomes, so comparisons are difficult to make[19]. Pritchett demonstrated strong patient preference for a BCR (89%) compared with other TKA designs in patients who underwent staged bilateral TKA[18]. The overall risk of revision was higher in the BCR group (5% versus 1%). The reasons for revision included 12% for polyethylene wear and 4% for aseptic component loosening[19].

Tsai et al. evaluated 30 patients who underwent unilateral BCR TKA; they all had pre-operative varus deformity and were operated by a single surgeon. They concluded no statistical significant difference in anterior-posterior translation as well as varus rotation, when compared to normal healthy knees in the stance phase. However, sagittal plane motion and tibiofemoral articular contact characteristics, including pivoting patterns, were not fully restored in BCR TKA during gait. This suggests that BCR TKA does not restore native tibiofemoral articular contact kinematics[4].

As mentioned earlier, literature shows the important stabilizing role of the ACL in the knee[6]. Keeping the ACL when performing TKA is attracting attention amongst surgeons. Okade et al. performed a biomechanical investigation of ACL function following BCR TKA compared with that in the intact knee on 8 cadaveric knees. The preserved ACL in the BCR TKA knees was functional, like in the intact knee, under anterior tibial loading and contributed to good AP stability. However, the ACL in the BCR TKA knees

functioned differently during passive flexion-extension movements, demonstrating higher tension and different kinematics compared with those in the intact knees[7].

A retrospective case-controlled study provided a short-term radiological and clinical comparison between the BCR and CR TKA. The cohort group consisted of 122 patients undergoing TKA with patient specific implant (PSI). Outliers of the Hip-Knee-Ankle axis occurred significantly more frequent in the BCR group (37,7%) compared to the CR (18,0%). No significant difference of the presence of exceeded AP-laxity were shown as measured with the Lachman test. No significant differences were observed in early revision rates or in ROM between the two groups at 2-years follow-up. This contradicts prior research stating increased stiffness in BCR TKA, hypothetically due to preservation of ACL. Kalaai et al. describe the BCR TKA is more sensitive to be implanted too tight than a CR-TKA, resulting in loss of ROM. This highlights the importance of adequate surgical training[20].

Pritchett performed 639 TKA in 537 patients from January 1989 to September 1992. He used in 489 a bicruciate retaining implant design. The mean follow-up of implant survivorship was 23 years with revision for any reason as the primary endpoint. He described a satisfactory survivorship of 89% at 23 years. The most common reason for revision was polyethylene wear[21].

A systematic review published in 2021 (De Mulder et al.) compared the clinical results of nine different BCR implants throughout history, the oldest being introduced in 1970s and the newest in 2010. The designs had good functional results, but all showed a high incidence of complications, mostly attributed to loosening and infection. Other reports hypothesize the cause to be multifactorial: malalignment, insufficient cementing, imprecise fitting and inadequate placement. It is stated that a substantial amount of these complications could be caused by inexperience of the surgeon. The authors experienced difficulties quantifying the heterogeneous outcome parameters of different studies[1]. Different scoring systems are being used, which makes it difficult to properly compare clinical results. Theodoulou et al. described 86 different scoring systems in 438 articles[22].

De Mulder et al. investigated the two new implant designs of BCR: Vanguard XP (Zimmer Biomet) and Journey XR (Smith&Nephew). In 2021 there were no articles reporting on the results of the Journey XR prosthesis published. Still to this day no articles were found. There are only three articles on the new Vanguard XP design, although clinical results are promising, the use cannot be justified based alone on the results of these three studies. New implant designs show good functional results, but still a high rate of loosening[1].

Osmani et al. published a systematic review in 2016 on the utility of BCR. Although BCR kinematics mirror the native knee more closely, overall there did not seem to be a significant difference in short-term clinical outcomes between the BCR and the cruciate retaining implant[23].

Many surgeons abandoned the use of BCR TKA due to its perceived technical difficulties, regularly causing various complications. We previously mentioned some of these complications such as loosening, infection and polyethylene wear[24]. In literature we found case reports on additional complications following BCR TKA.

With the first design of the BCR TKA, avulsion fracture of the remaining tibial spine was a recurring problem, particularly seen with the knee near full extension. An update of the tibial tray improved this complication, but was not a complete elimination of the problem. The reason of this avulsion was possibly due to increased ACL forces caused by the insertion of the implant. We suggest preserving as much of the ACL bony attachment as possible to avoid avulsion fractures of the tibial eminence[6]. Chu-Man Lau et al. published a case report in 2022 on a 70-year old woman who had single-stage bilateral knee primary BCR TKA for end-stage osteoarthritis. She developed a significant degree of instability in the left knee 3 weeks post surgery during physiotherapy. There was no direct injury or fall. The contralateral right knee was asymptomatic with a good range of motion and no demonstrable laxity. A CT-scan of the left knee showed a fracture of the intercondylar area that included the ACL insertional area. It extended posteriorly to include the PCL insertional area and anteroinferiorly with concomitant partial patellar tendon avulsion. During revision surgery to a conventional PS TKA a complete ACL and PCL avulsion was found[16].

Arthrofibrosis is a serious complication following surgery of the knee; the associated loss of motion is poorly tolerated. It is one of the main causes of dissatisfaction after TKA, especially in the younger, more active patient. The cyclops lesion is a complication following arthroscopically assisted ACL reconstruction, first described by Jackson and Schaefer in 1990. Klaassen et al. published a case report, which describes 3 cyclops lesions in 2 patients (1 bilateral) following BCR TKA[25]. The cyclops lesion blocks full extension of the knee. After arthroscopic excision of the large cyclops lesion, full extension of the knee was gained. The lesion should be suspected following BCR TKA when full extension cannot be achieved despite

intense physiotherapy, especially if full extension was achieved postoperatively and then lost[25].

DISCUSSION

The ACL is commonly sacrificed during TKA, but there is some evidence that retention of the ACL could result in superior kinematics after surgery[21]. BCR TKA may offer an effective solution with improved functional implants that better reconstruct natural knee kinematics. To our knowledge this is the most recent systematic literature review on the BCR TKA topic. Previously, only De Mulder et al. published a review about results throughout history (2021) and Boese et al. did a systematic literature review on clinical outcomes of BCR TKA (2020)[1,2]. Da Faoite et al. just did a survey that showed a strong interest in BCR TKA by orthopaedic surgeons, but limited experience and use[15]. The use of BCR implants remains controversial because of technical difficulty, inconclusive benefit and increased risk of complications[1]. Lack of surgeon enthusiasm for BCR TKA might be attributed to the challenging difficulties of the procedure[6]. Available literature on BCR TKA does not specify indications in a precise manner. There is a significant overlap between recent unicompartmental and bicompartmental knee replacement indications that may be confusing[3]. The lack of clear guidance and indications prevent its use[15].

The BCR TKA demonstrates anterior drawer laxity, total AP laxity and neutral range of motion significantly closer to the native knee than the CR TKA[6]. On evaluating AP laxity in BCR TKA in the stance phase, no significant difference was present when compared to normal healthy knees. Overall a very good AP stability was obtained. Nevertheless, BCR TKA did not restore the native tibiofemoral articular contact kinematics during the gait phase[4]. Furthermore, the ACL in the BCR TKA knees functioned differently during passive flexion-extension movements, demonstrating higher tension and different kinematics compared with those in the intact knees[7].

The BCR TKA is more sensitive to be implanted too tight than a CR TKA, resulting in loss of ROM. This highlights the importance of adequate surgical training[20]. When learning a new procedure, performance tends to improve with experience. The importance of the learning curve for performing the BCR TKA should not be underestimated. In literature we could not find an exact guideline or description on the orientation of the tibial tray in BCR TKA. The accuracy of component orientation may ideally be provided by the use of additional surgical navigation or robotic assistance. To our knowledge there are no reports that have investigated this possible advantage on BCR TKA outcomes so far.

So far we have not found substantial superior clinical outcomes of the BCR TKA compared to other designs. Different scoring systems are being used, which makes it difficult to properly compare results[22]. There was no significant difference in short-term clinical outcomes between the BCR and the CR implant[23]. The technical difficulties and learning curve could be responsible for the high incidence of complications. The most common reason for revision was polyethylene wear, followed by loosening and infection[21]. Some reports hypothesize the cause of revision to be multifactorial: malalignment, insufficient cementing, imprecise fitting and inadequate placement. This shows a substantial amount of complications could be caused by inexperience of the surgeon[1]. Other complications earlier described, such as avulsion fracture of the remaining tibial spine, arthrofibrosis and cyclops lesion, remain difficulties we're facing even with the newer BCR implant designs[1,6,16,25].

We also like to mention the preference of the patient. A prospective study on 440 patients concluded patient's preference for a BCR TKA in 89% compared with other TKA designs in those who underwent bilateral staged total knee arthroplasty[18]. Yet, another study comparing the BCR to CR TKA failed to demonstrate any differences in patient-reported outcomes between the two groups[19].

CONCLUSION

In conclusion: Based on this review the use of BCR TKA is still debatable. To this day, no substantial benefit could be demonstrated. Old and newer designs show good functional results, but still a high rate of complications. Literature has not disclosed proper indications and guidelines for the use of BCR implants so far. The accuracy of component orientation may ideally be provided by the use of additional surgical navigation or robotic assistance. We would suggest image-based navigation or robotics, as the rotational and sagittal alignment is key. Imageless systems fail to yield accurate results in the horizontal and sagittal plane. To our knowledge there are no reports that have investigated this possible advantage on BCR TKA outcomes. It is possible that an extensive amount of complications is caused by inexperience of the surgeon. We advise for a large independent randomized clinical trial with surgeons who are experienced with the BCR TKA implant to cancel out potential learning curve.

Long-term follow-up studies are needed to compare the clinical results between different prostheses. We also like to address the need for regularity in standardized scoring systems to improve comparability of clinical and patient reported outcome measures. We conclude there still is no consensus on the strict limitations and indications of BCR TKA. Further research is advocated to provide the required evidence of bicruciate retaining total knee arthroplasty in the future.

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