

Bone & Joint Science

Our Innovation in Focus

The Evolution of Guided Motion Total Knee Arthroplasty: The JOURNEY[◇] II Bi-Cruciate Stabilized Knee System

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Summary

Functional outcomes are compromised in approximately half of all TKA patients. This loss is caused primarily by the anatomically inaccurate articular geometry and instability inherent to contemporary implants. The JOURNEY Bi-Cruciate Stabilized (BCS) Knee System (Smith & Nephew, Inc., Memphis, TN, USA) was the first TKA device to provide anterior-posterior stability throughout knee flexion, while enabling posterior femoral translation and external rotation inherent to the normal, healthy knee. Together, these design features were thought to improve functional outcomes following TKA. The efficacy of this guided motion concept has since been verified in the published clinical literature. However, recent

evidence has highlighted the potential for iliotibial band (ITB) syndrome or dislocation in some patients. Therefore, the latest virtual musculoskeletal modeling technology has been utilized to identify the key design parameters affecting the soft-tissue envelope in TKA. This extensive research has led to the development of the JOURNEY II BCS knee system (Smith & Nephew, Inc., Memphis, TN, USA), a recently validated design that combines the proven guided motion concept with physiological soft-tissue interaction and accountability. This system represents the next evolutionary step towards consistently restoring natural knee function following TKA.

Introduction

There is little debate regarding the safety and efficacy of modern total knee arthroplasty (TKA). This surgery routinely supports significant reductions in pain, as well as a quick return to activities of daily living [1–3]. However, relatively young and demanding patients are commonly unsatisfied with their functional outcomes following TKA [3–5]. Approximately half of all active patients appear to experience some loss of postoperative knee function, particularly during deep-flexion activities [1, 4, 5]. While many factors can affect these outcomes, this loss appears to be caused primarily by the altered articular geometry and instability inherent to contemporary TKA implants [6–8].

Natural knee motion begins with the screw-home mechanism [9]. From a slightly anterior and internally rotated position in full extension, the femur rotates externally and rolls

backwards over the tibial plateau during mid-flexion. In deep-flexion, there is relatively greater translation of the lateral femoral condyle. These characteristics support full range of motion at the knee, while also improving quadriceps muscle function during squatting, kneeling, or lunging activities through biomechanical reduction of the Q-angle [10–12]. In contrast, femoral motion following conventional TKA is typically characterized by paradoxical anterior sliding and insufficient axial rotation [6]. This instability and malrotation significantly reduces the efficiency of the extensor and flexor musculature, which adversely alters the kinematics and joint moment patterns of the knee [13–15]. Without natural motion in TKA, optimal postoperative clinical and functional outcomes cannot be achieved [1, 6, 11, 13].

It must be noted that contemporary TKA has evolved to include asymmetrical posterior cruciate ligament (PCL) retaining and

stabilized designs. While both have served to improve functional outcomes, posterior stabilized (PS) knee systems have demonstrated more natural kinematics [1, 13]. However, none of these systems replicate the essential function of the anterior cruciate ligament (ACL), which stabilizes the knee joint and enables muscular efficiency [15]. Furthermore, many posterior cruciate retaining (PCR) and PS designs feature anatomically inaccurate concave or conforming articular geometries that are incapable of allowing external femoral rotation [7]. Alternatively, the real key to normal knee function in TKA is to create an implant design that restores the replaced anatomy of the normal knee, enabling normal kinematics, biomechanics, and muscular efficiency. It is that desire for restoration of all essential elements that led to the introduction of the first bi-cruciate stabilized TKA system.

Restoring the Normal Knee

The JOURNEY[®] Bi-Cruciate Stabilized (BCS) Knee System (Smith & Nephew, Inc., Memphis, TN, USA) was first introduced in 2005. This knee system was designed to restore normal knee function by increasing anterior-posterior stability throughout knee flexion and promoting a normal kinematic pattern. This was made possible by a few novel design features. First, the JOURNEY BCS knee featured an anatomically correct joint line and articulating surface. As with the natural tibial plateau (Figure 1a), the tibial insert was designed with a concave medial and convex lateral shape, providing medial stability and increased relative posterior translation of the lateral condyle with flexion (Figure 1b). Second, JOURNEY BCS was designed with an inherent screw-home mechanism, supporting a relative anterior and internally rotated femoral position in extension (Figure 2a) [9]. Stability in extension was enhanced via the femoral cam-tibial post construct, which replicated function of both the ACL and PCL. During flexion, the asymmetric cam maintained full contact with the post while externally rotated to ensure anterior stability and quadriceps efficiency during posterior translation (Figure 2b). Together, these features enabled the first guided motion design in contemporary TKA.

Initially, the guided motion of the JOURNEY BCS knee was confirmed during virtual simulation testing. Design parameters were imported into a validated musculoskeletal modeling system (LifeMOD/KneeSIM; LifeModeler, Inc., San Clemente, CA, USA) in order to assess joint kinematics and kinetics during flexion, as compared to a healthy knee model derived from MRI imaging data [16]. Inputs from simulation testing

Figure 1a–b: Tibial plateau of the natural knee, featuring a concave medial surface and a convex lateral surface (a). Physiologic joint line and asymmetric, anatomically accurate design of the JOURNEY[®] BCS femoral component and tibial insert (Smith & Nephew, Inc., Memphis, TN, USA; b)

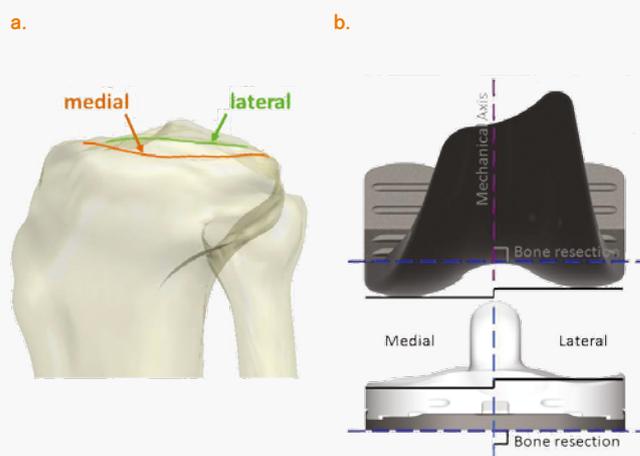


Figure 2a–b: Superior view of the JOURNEY BCS femoral component demonstrating the internally rotated position of the femur in extension (a), and engagement of the asymmetric cam during deep flexion and posterior translation of the lateral condyle (arrow; b)



were then utilized in three-dimensional finite element models of the articulating surface to assess insert contact pressures and potential wear performance. Ultimately, these tests provided assurance that the motion of JOURNEY[®] BCS was comparable to that of the normal, healthy knee. Published clinical evidence has since corroborated these initial observations.

Catani and colleagues [6] assessed knee joint kinematics in 16 JOURNEY BCS patients. Video-fluoroscopy and electromyography (EMG) were used to assess gait and muscle activation during activities of daily-living, including stair climbing, chair rising and sitting, and a step-up/down test. Following analysis, all patients demonstrated a combination of relatively normal locomotion and gait, coupled with clear femoral external rotation and translation.

This resulted in the recovery of normal extensor and flexor muscle function, which was attributed to the anatomic implant design. Similar results have been reported by Kuroyanagi and colleagues [1], who recently assessed in vivo kinematics in 20 JOURNEY BCS patients. Video-fluoroscopy was used to record knee motion during stair climbing and descent, lunging, and kneeling activities. When compared to PCR and PS patients, the JOURNEY BCS group demonstrated knee kinematics and femoral rotation that were qualitatively more similar to that of unoperated knees. Furthermore, the authors noted anatomical flexion of 133° in the JOURNEY BCS group, which is one of the largest values reported in the literature [12, 17, 18]. While not perfectly matching the normal knee, the authors noted that this implant design was the next evolutionary step towards achieving truly natural function.

While the dynamics of femoral rollback and external rotation occurring at the appropriate ranges of motion appear to be required for normal knee function, it is also important to consider patellofemoral kinematics after TKA. Using simulated weight bearing during magnetic resonance imaging (MRI), Carpenter et al [19] assessed patellar kinematics and contact stress in JOURNEY BCS and PCR patients. Results of this study suggest that the more normal tibiofemoral kinematics of the JOURNEY BCS knee support reduced patellar contact stress and normal tilt during full extension and early flexion. This finding is particularly relevant to clinicians because, as reported by the authors, upwards of 50% of all TKA revisions are due to patellofemoral complications [1, 20–23].

Iliotibial Band Traction and Dislocation

Published clinical evidence clearly supports the efficacy of guided motion [1, 6, 19]. However, two recent publications have highlighted potential complications associated with JOURNEY BCS. First, some patients have presented with an increased incidence of Iliotibial band (ITB) syndrome. Luyckx and colleagues [24] reported outcomes for 1,070 JOURNEY[®] BCS knees at a mean follow-up of 2.5 years. Overall, clinical outcomes for this cohort were quite good. Device survival of 98% was reported, with partial or total revision as the primary endpoint. However, symptoms of iliotibial band (ITB) syndrome were observed in 7.2% of patients at a mean of six months follow-up. After further rehab, pain during flexion persisted in 2% of these patients, resulting in surgical ITB release. The authors suggest that excessive translation of the femur in flexion can lead to increased eccentric loading of the ITB in some patients, potentially causing the pain. Furthermore, it is noted that this motion in the normal knee is limited by co-contraction of the biceps femoris [25]. These results suggest that limiting the degree of translation in guided motion TKA during specific ranges of motion can effectively eliminate ITB complication risk.

In addition to ITB traction, complications associated with dislocation have been reported. Arnout et al [26] cite four cases of femoro-tibial dislocation in JOURNEY BCS patients (0.3% incidence). The authors state that each case demonstrated excellent clinical outcomes at the time of dislocation. However, each of these patients also happened to be extremely flexible, achieving deep-flexion quickly after surgery. The dislocations all occurred during varus-flexion or flexion-rotation, routine motions that are required during activities of daily living, such as putting on socks or crossing one's legs. This movement allows the femoral cam to potentially jump over the relatively short tibial post. The authors recommend careful intraoperative joint balancing to address dislocation risk. Of note, the same phenomenon has been recently reported by Jung et al [27], who cite a 5.2% incidence of dislocation with the Columbus[®] posterior stabilized high-flexion knee prosthesis (B. Braun Aesculap, Tuttlingen, Germany). While this incidence is considerably higher than that observed for JOURNEY BCS, the mechanism of a superiorly rounded, short tibial post jump distance is the same.

The Journey Continues: Guided Motion Refined

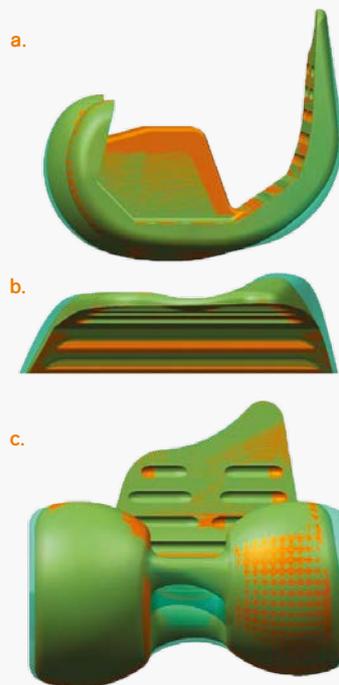
JOURNEY BCS was the first TKA device of its kind. While the evidence suggests that the goal of achieving more normal kinematics was certainly achieved, the implementation of guided motion did create some unique challenges. Specifically, unrestrained lateral rollback of the femur does appear to increase the risk for antero-lateral knee pain or dislocation in some patients [24, 26]. This device limitation can be attributed to the originally utilized design tools. When the first guided motion TKA concept was tested within the virtual LifeMOD/KneeSIM environment, the ligament structures or soft-tissues of the knee were modeled very simplistically. This rudimentary methodology simply provided confirmation of the geometry and basic function of the articular surfaces. Fortunately, KneeSIM software has been updated to support more robust analyses. Following a comprehensive literature search, detailed anatomical and function characteristics of the ITB, IT-patellar bands (ITPB), and other ligament structures of the knee were imported into the new validated, virtual model. This has allowed ligament stretch and strain to be accurately assessed during the design of a refined guided motion implant.

The JOURNEY[®] II BCS Knee System (Smith & Nephew, Inc., Memphis, TN, USA; Figure 3) is the next evolutionary step towards natural motion in TKA, coupling proven tibiofemoral kinematic performance with physiological soft-tissue robustness. This is enabled by several key design adjustments. The dimensions of the femoral component have been adjusted to reduce soft-tissue strain and maintain more natural translation and external rotation (Figure 4). The lateral and medial anterior flange of the femoral component has been reduced in thickness by 1–2 mm and tapered at the edges, which contributes to reducing tension on the ITB and ITPB. The width of the femoral was decreased 2–3 mm to limit implant overhang, and the mid-flexion thickness of the medial condyle was reduced to maintain more consistent strain on the medial-collateral ligament (MCL) throughout the flexion range. Furthermore, Figure 4C demonstrates the superior cam position in JOURNEY[®] II BCS, which serves to decrease femoral rollback in the targeted ranges of motion, increase femoral external rotation, and lower the point of tibial post contact in deep-flexion.

Figure 3: The JOURNEY[®] II BCS Knee System (Smith & Nephew, Inc., Memphis, TN, USA)



Figure 4a–c: Key JOURNEY II BCS femoral component design changes. The green and orange overlay represents the dimensions of the JOURNEY BCS and JOURNEY II BCS femoral components, respectively. Shown are the lateral (a), superior (b), and posterior (c) views.



Changes to the JOURNEY II BCS tibial post are illustrated in Figure 5. The position of the post is now anterior to the original JOURNEY BCS design, and the height has been increased. This increase in height is accommodated by taller PS femoral box walls. The function of the new post is two-fold. First, the position of the post serves to further maintain more anatomically correct femoral rollback, reducing ITB and ITPB tension. Second, the height of the tibial post balances patellar impingement while maximizing the dislocation safety factor in flexion (Figure 5c).

The performance of JOURNEY II BCS has been validated in two different models. The updated LifeMOD/KneeSIM allows detailed modeling of ligament length change and strain during flexion, in addition to assessment of tibiofemoral kinematics. Available ligament strain data is presented in Figures 6a, 6b, and 6c.

First, it is important to note the relatively increased mid-flexion ITPB, ITB, and MCL strain for JOURNEY BCS. The KneeSIM model can now virtually confirm the potential for ITB traction with this design, as evidenced by approximately 0.16, 0.13, and 0.06 mm/mm of estimated strain for the ITPB, ITB, and MCL, respectively. Moreover, the observed mid-flexion ligament strain for JOURNEY II BCS is quite similar to that produced by the GENESIS® II PS knee (Smith & Nephew, Inc., Memphis, TN, USA), a clinically successful legacy device with no known incidence of ITB syndrome [28].

Figure 5a–c: Tkey JOURNEY II BCS tibial component design changes. The green and orange overlay represents the dimensions of the JOURNEY BCS and Journey II BCS tibial components, respectively. Shown are the lateral (a) and posterior (b) views, along with an illustration of dislocation safety distance (c).

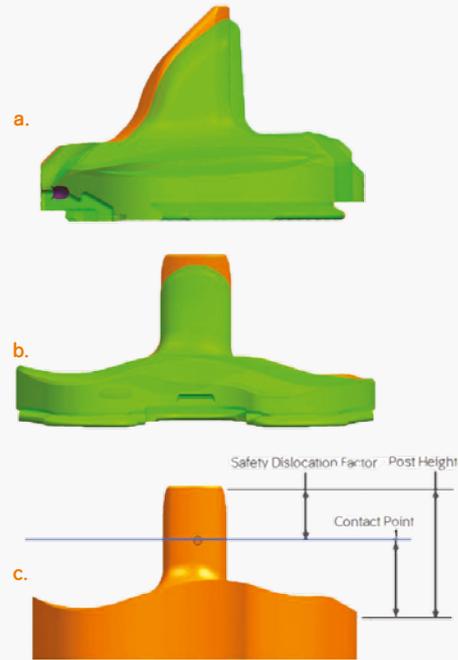
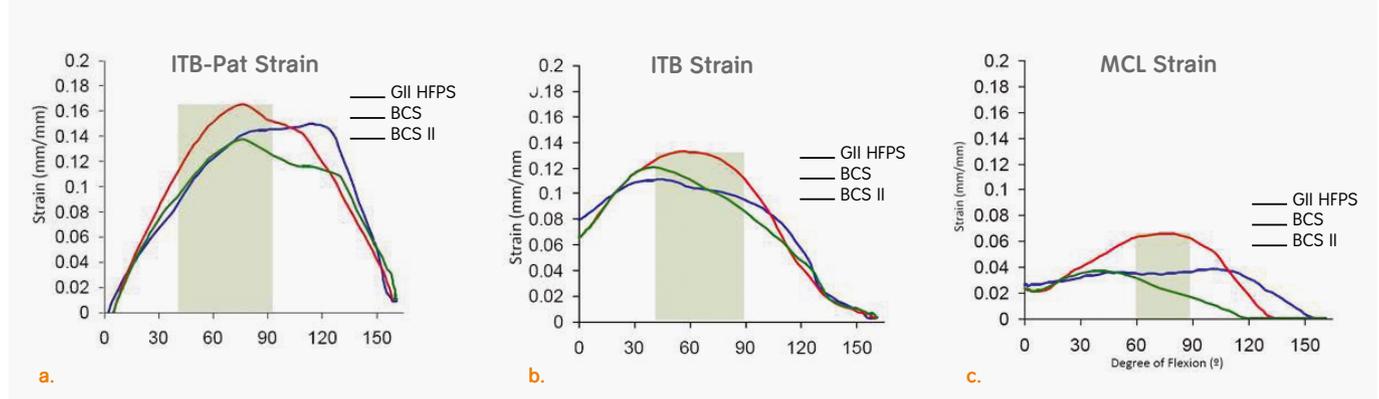


Figure 6a–c: TlifeMOD/KneeSIM I TPB (A), ITB (B), and MCL (C) strain data.



In addition to maintaining physiological soft-tissue function, it is also critical that the JOURNEY II BCS knee demonstrates the desired tibiofemoral kinematics. KneeSIM data confirms the two essential elements of natural knee motion (Figure 7). First, translation of the JOURNEY II BCS medial femoral condyle is more similar to that of the normal knee during flexion [9], as compared to JOURNEY BCS and the LEGION[®] PS knee (Smith & Nephew, Inc., Memphis, TN, USA). Second, translation of the JOURNEY II BCS lateral condyle is approximately equal to that of the normal knee. This is in contrast to the translation observed for JOURNEY BCS, which exceeds that of the normal knee.

Virtual modeling software has proven to be a very effective tool in the design of JOURNEY II BCS. However, this refined guided motion design has been further validated during a recently completed in-vitro study [29]. This study was designed to assess soft-tissue behavior in the JOURNEY II BCS knee, as compared to JOURNEY BCS and GENESIS II. The experimental set-up was consistent with the methods of Gosh et al [30], and was designed to simulate activity of the quadriceps musculature during flexion. Linear variable displacement transducers were utilized to measure length changes and potential strain in the ligaments of each implant group. While the differences in ligament length between the knee groups were limited, the authors did note tightening of the ITB past 50° flexion in the JOURNEY BCS group (Figure 8). This observation is consistent with the reported clinical evidence [24] and latest virtual modeling results. What is more interesting, however, is that the ITB length of JOURNEY II BCS was most similar to that of the intact, normal knee. Together with the previously discussed clinical and KneeSIM data, these study results provide assurance that the JOURNEY II BCS design has effectively addressed the previously identified limitations, while improving its kinematic performance. Moreover, the evidence as a whole firmly establishes the efficacy of the JOURNEY concept in TKA.

Figure 7a–b: LifeMOD/KneeSim kinematic data for medial (a) and lateral (b) femoral AP motion.

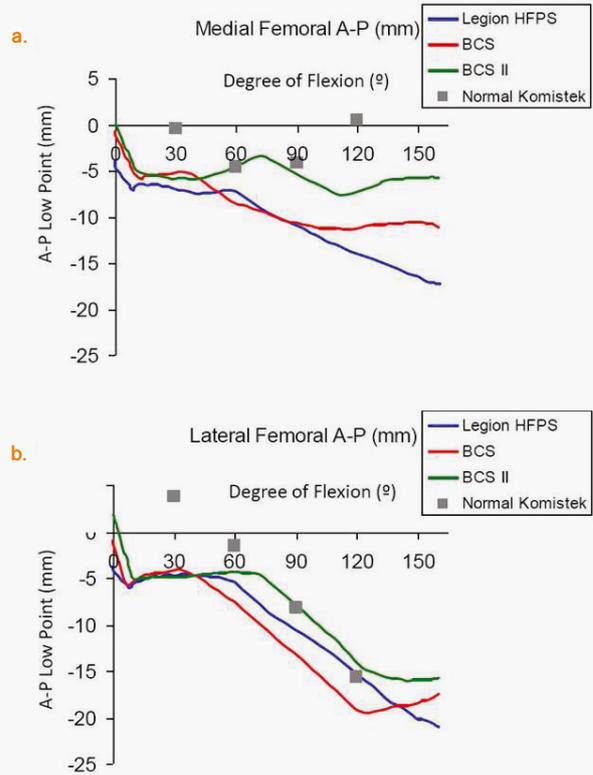
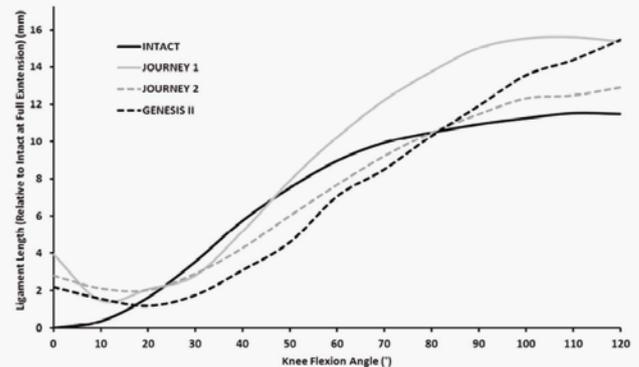


Figure 8: Deep ITB length of TKA devices, relative to the intact knee at full extension [29]



Conclusion

The original JOURNEY BCS knee system introduced the concept of guided motion in TKA with functional success. To date, all published kinematic evidence has demonstrated tibiofemoral motion that is quantitatively and qualitatively more similar to that of the normal knee. With the introduction of JOURNEY II BCS, the proven guided motion concept has been coupled with a refined design that maintains consistent soft-tissue envelope robustness. Early simulation and in-vitro testing results have validated the JOURNEY II BCS knee refinements. Moreover, Smith & Nephew is currently in the process of initiating several clinical studies which will further assess device performance during short and long-term follow-up. All study results will be reported to the community as soon as they are available.

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