Original Article

Bicruciate Substituting Total Knee Arthroplasty Improves Stair Climbing Ability When Compared with Cruciate-Retain or Posterior Stabilizing Total Knee Arthroplasty

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Abstract

Purpose: The purpose of this study was to compare stair climbing and descent ability following bicruciate substituting (BCS), cruciate retaining (CR), and posterior stabilizing (PS) total knee arthroplasties (TKAs). **Materials and Methods:** Sixty-three participants undergoing BCS-TKA (journey II: Smith and Nephew), 47 participants undergoing CR-TKA (FINE: Teijin Nakashima Medical), and 38 participants undergoing PS-TKA (FNK: Teijin Nakashima Medical) were included in this study. Before and 12 months after surgery, a questionnaire was administered to assess daily stair climbing and descent ability. In the questionnaire, stair climbing and descent ability were classified as (1) stair climbing and descent one step at a time, (2) stair climbing and descent two steps at a time, and (3) unable to climb or descend stairs. The necessity of a handrail was also evaluated and classified as: (1) necessary, (2) unnecessary, and (3) unable to climb or descend stairs with handrail. Statistical analysis (χ^2-test) was performed to compare these data between the types of TKA. **Results:** Preoperatively, no significant differences in stair climbing and descent ability or between handrail classifications were observed between the three different TKA groups. Postoperatively, the percentage of patients able to climb stairs one step at a time was significantly higher in BCS-TKA group (89%), when compared with CR (72%) or PS (58%) TKA groups. No significant differences in stair descent ability or among the handrail necessity classifications were observed between the types of TKA. **Conclusion:** BCS-TKA resulted in significantly better stair climbing ability when compared with CR or PS-TKA. This may indicate that the design of BCS-TKA better reproduces native anterior cruciate ligament and posterior cruciate ligament function and improves knee stability during stair climbing activity.

Keywords: *Bicruciate substituting, osteoarthritis, stair, total knee arthroplasty*

Introduction

Although many participants who undergo total knee arthroplasty (TKA) for the treatment of severe knee osteoarthritis (OA) obtain excellent clinical results,[1-5] it has also been reported that normal knee kinematics and function are not accurately reproduced in traditional TKA designs.[6-10] As the demand and frequency of TKA grows, the degree of satisfaction reported has been relatively low.[9-13] One potential cause may be that conventional TKA designs cannot reproduce normal knee kinematics and function due to the lack of the anterior cruciate ligament (ACL).[6,7,10,12] In cruciate retaining (CR) and posterior stabilizing (PS) TKA procedures, the ACL is always resected, which can cause abnormal tibiofemoral positioning in the range of knee motion (ROM) and anterior knee laxity.[8,13-16] In traditional CR and PS-TKA procedures, paradoxical anterior sliding of the femoral bone and insufficient femoral rotation in the ROM have been reported.[9,10,17] It has been suggested that this paradoxical movement of the femoral bone results in the loss of knee flexion.[3,4,18]

Recently, bicruciate substituting (BCS) TKA has been developed for the purpose of obtaining better knee function and kinematics similar to that of normal knees.[6,8,10,17,19] In the BCS-TKA design, to restore normal knee function by increasing anterior-posterior stability throughout knee flexion and promoting a normal kinematic pattern, the tibial insert is designed with a concave medial and convex lateral shape, providing medial stability and increased relative posterior translation of the lateral condyle with flexion.

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Furthermore, BCS-TKA is designed with an inherent screw-home mechanism, supporting a relative anterior and internally rotated femoral position in extension. Stability in extension is enhanced by the characteristic femoral cam-tibial postdesign. In the post and cam design of BCS-TKA, both ACL and posterior cruciate ligament (PCL) function are replicated. During ROM, the tibial post is in full contact with the femoral cam while externally rotated to ensure anterior stability and quadriceps efficiency during posterior translation. Several studies have reported similar knee kinematics in BCS-TKA with normal knee function and favorable clinical results.[6,8,10,19,20] However, to the best of our knowledge, few studies have addressed *in vivo* biomechanics in BCS-TKA, especially in the newly introduced journey II BCS (Smith and Nephew, Memphis, TN, USA).

The purpose of this study was to compare stair climbing and descent ability in BCS, CR, and PS-TKAs.

The hypothesis was that stair climbing and descent ability would be different in the types of TKAs.

Materials and Methods

This is a case controlled study. Sixty-three participants undergoing BCS-TKA (journey II: Smith and Nephew), 47 participants undergoing CR-TKA (FINE: Teijin Nakashima Medical), and 38 participants undergoing PS-TKA (FNK: Teijin Nakashima Medical) were included in this study [Figure 1]. Before and 12 months after surgery, a questionnaire was administered to assess daily stair climbing and descent ability. In the questionnaire, stair climbing and descent ability were classified as:

1. Stair climbing and descent one step at a time
2. Stair climbing and descent two steps at a time
3. Unable to climb or descend stairs.

When people have minimal or no pain and have normal lower limb function, they could climb or descent one stair with one step. Moreover, when people have some pain and have insufficient lower limb function, two steps would be needed to climb or descent one stair.

The necessity of a handrail was also evaluated and classified as:

1. Necessary
2. Unnecessary
3. Unable to climb or descend stairs with handrail.

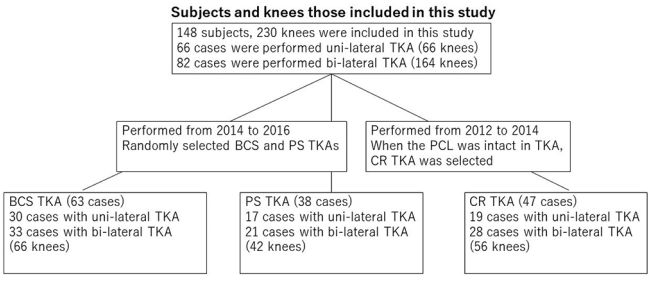

Figure 1: The flow chart of the participants and knees those included in this study

The preoperative diagnosis of all participants was OA. Participants with rheumatoid arthritis and participants with any history of knee trauma were excluded from this study. All the participants provided written informed consent for the participation in the study. All procedures performed in the study were conducted in accordance with the ethical standards given in 1964 Declaration of Helsinki, as revised in 2013. All data were compiled retrospectively and obtained from medical records. The questionnaire was performed by the physical therapists.

Surgical procedures

All surgeries were performed under general anesthesia by a single surgeon (R. K). Knees were opened with a medial parapatellar approach. An air tourniquet was used with 300 mmHg. Before bone cut, the surrounding bony spurs were resected on both the femoral and tibial sides. The ACL and PCL were resected in both the BCS-TKA and PS-TKA groups. Bone resection was performed as a measured resection technique using a spacer block. CR-TKA was performed from 2012 to 2014. In such procedures, when the intact PCL was confirmed during the surgery, the PCL was left intact and CR-TKA was selected as the surgical technique. Patellar resurfacing was performed in all knees. No lateral soft-tissue release was performed. The BCS and PS-TKAs included in this study were performed from 2014 to 2016. During this period, BCS or PS-TKAs were randomly selected. No specific indications were existed for the selection of BCS-TKA.

This study was approved by the ethics committee of Kamimoku hot springs hospital.

Statistical analysis

Data are presented as the mean ± standard deviation. Comparisons of data (age and ROM) were made between the groups (Kruskal–Wallis test). The percentage of bilateral cases, the percentages among the stair climbing and descent classifications, and the percentages among the handrail necessity classifications between the groups were compared using a χ^2-test. Collected data were analyzed using SPSS for Windows, version 21.0 (SPSS Inc., Chicago, IL, USA) software. Values were considered significantly different at $P < 0.05$. Considering the mean and standard deviations in the ROM, the calculated sample size of each group was 34.

Results

No significant group difference in age, gender, ROM, Kellgren-Lawrence grade, femorotibial angle (FTA), preoperative knee society score (KSS), or percentage of bilateral cases was observed in Table 1. No significant difference of the postoperative ROM, FTA, and the KSS was also observed between the groups [Table 1]. No severe complication was observed in this study.

Stair climbing ability

In preoperative stair climbing ability, the percentages of one step at a time, two steps at a time, and unable to climb stairs in the BCS-TKA group were 8% (n = 5), 59% (n = 37), and 33% (n = 22), respectively. In the CR-TKA group, the percentages were 13% (n = 6), 57% (n = 27), and 30% (n = 14), respectively. In the PS-TKA group, the percentages were 5% (n = 2), 61% (n = 23), and 34% (n = 13), respectively. No significant statistical difference in preoperative stair climbing ability was observed. In postoperative stair climbing ability, the percentages of one step at a time, two steps at a time, and unable to climb stairs in the BCS-TKA group were 89% (n = 56), 10% (n = 6), and 1.6% (n = 1), respectively. In the CR-TKA group, the percentages were 72% (n = 32), 28% (n = 13), and 0% (n = 0), respectively. In the PS-TKA group, the percentages were 58% (n = 22), 37% (n = 14), and 5% (n = 2), respectively. The BCS-TKA group showed significantly better postoperative "one step at a time" stair climbing ability when compared with the CR and PS-TKA groups ($P < 0.05$) [Table 2].

Stair descent ability

In preoperative stair descent ability, the percentages of one step at a time, two steps at a time, and unable to descend stairs in the BCS-TKA group were 3% (n = 2), 63% (n = 40), and 33% (n = 21), respectively. In the CR-TKA group, the percentages were 8% (n = 4), 62% (n = 29), and 30% (n = 14), respectively. In the PS-TKA group, the percentages were 0%, 66% (n = 25), and 34% (n = 13), respectively. No significant statistical difference in preoperative stair descent ability was observed. In postoperative stair descent ability, the percentages of one step at a time, two steps at a time, and unable to descend stairs in the BCS-TKA group were 59% (n = 37), 40% (n = 25), and 1.6% (n = 1), respectively. In the CR-TKA group, the percentages were 49% (n = 23), 51% (n = 24), and 0%, respectively. In the PS-TKA group, the percentages were 45% (n = 17), 50% (n = 19), and 5% (n = 2), respectively. No significant statistical difference in postoperative stair descent ability was observed among the three groups [Table 3].

Necessity of handrail

Preoperatively, the percentages of handrail necessary, handrail unnecessary, and unable to climb or descend stairs with handrail in the BCS-TKA group were 65% (n = 41), 1.6% (n = 1), and 33% (n = 21), respectively. In the CR-TKA group, the percentages were 70% (n = 33), 0% (n = 0), and 30% (n = 14), respectively. In the PS-TKA group, the percentages were 66% (n = 25), 0% (n = 0), and 34% (n = 13), respectively. Preoperatively, no significant statistical difference among the necessity of handrail classifications was observed among the three groups.

Table 1: Background of participants

	BCS	CR	PS
Number (bi-lateral case)	63(33)	47(28)	38(21)
Age	75.2±7.8	76.4±8.4	78.6±5.8
Gender	F 52 M 11	F 38 M 9	F 31 M 7
KL classification (knees)	KL4(82), KL3(14)	KL4(68), KL3(7)	KL4(50), KL3(9)
Pre-operative ROM	121±7.7°	118±5.4°	118±8°
Post-operative ROM	121.5±7.5°	116±7.4°	115±7.3°
Pre-operative FTA	184.3±4.1°	184±6.2°	186.1±4.3°
Post-operative FTA	176±2.7°	177.2±3°	177±2.1°
Pre-operative KSS	48±8.2	46.3±7.5	45.3±6.9
Post-operative KSS	84.2±9.5	82±7.2	81.7±11.3

No significant differences in age, gender, KL classification, pre and postoperative ROM, FTA, and KSS were observed between the groups. FTA=Femorotibial angle, KL=Kellgren-Lawrence, KSS=Knee society score, ROM=Range of motion

Table 2: Stair climbing ability

Pre-operative	One step at a time	Two steps at a time	Unable
BCS	5 (8%)	37 (59%)	21 (33%)
CR	6 (13%)	27 (57%)	14 (30%)
PS	2 (5%)	23 (61%)	13 (34%)

Post-operative	One step at a time	Two steps at a time	Unable
BCS*	**56 (89%)**	6 (10%)	1 (1.6%)
CR	34 (72%)	13 (28%)	0
PS	22 (58%)	14 (37%)	2 (5%)

*p<0.05

Postoperatively, the percentage of one step at a time was significantly larger in participants with BCS-TKA when compared with CR or PS-TKA. BCS=Bicruciate substituting, TKA=Total knee arthroplasty, CR=Cruciate-retain, PS=Posterior stabilizing

Table 3: Stair descent ability

Pre-operative	One step at a time	Two steps at a time	Unable
BCS	2 (3%)	40 (63%)	21 (33%)
CR	4 (8%)	29 (62%)	14 (30%)
PS	0	25 (66%)	13 (34%)

Post-operative	One step at a time	Two steps at a time	Unable
BCS	37 (59%)	25 (40%)	1 (1.6%)
CR	23 (49%)	24 (51%)	0
PS	17 (45%)	19 (50%)	2 (5%)

No significant difference in stair descent ability was observed between the groups pre or postoperatively. BCS=Bicruciate substituting, TKA=Total knee arthroplasty, CR=Cruciate-retain, PS=Posterior stabilizing

Postoperatively, the percentages of handrail necessary, handrail unnecessary, and unable to climb or descend stairs with handrail in the BCS-TKA group were 75% (n = 47), 24% (n = 15), and 1.6% (n = 1), respectively. In the CR-TKA group, the percentages were 77% (n = 36), 23% (n = 11), and 0%, (n = 0), respectively. In the PS-TKA group, the percentages were 89% (n = 34), 5% (n = 2), and 5% (n = 2), respectively. Postoperatively, no significant

Table 4: Use of handrails

Pre-operative	Necessary	Unnecessary	Unable
BCS	41 (65%)	1 (1.6%)	21 (33%)
CR	33 (70%)	0	14 (30%)
PS	25 (66%)	0	13 (34%)
Post-operative	**Necessary**	**Unnecessary**	**Unable**
BCS	47 (75%)	15 (24%)	1 (1.6%)
CR	36 (77%)	11 (23%)	0
PS	34 (89%)	2 (5%)	2 (5%)

No significant difference among the handrail necessity classifications was observed between the groups pre or postoperatively

statistical difference among the necessity of handrail classifications was observed [Table 4].

Discussion

The most important finding of this study is that BCS-TKA resulted in significantly better "one step at a time" stair climbing ability when compared with CR or PS-TKA. On the other hand, no significant differences in stair descent ability or among the handrail necessity classifications were observed depend between the TKA designs.

BCS-TKA (journey II) was designed to incorporate ACL and PCL function during ROM to achieve native knee kinematics.[6,8-10,12,19,21] Digennaro *et al*. reported that the BCS-TKA (journey) resulted in a better knee score when compared with PS-TKA (Scorpio NRG) in a 29-month followup.[7] However, Halewood *et al*. found that BCS-TKA (journey and journey II) could not reproduce native knee function in a cadaveric study.[8] Christen *et al*. reported that BCS-TKA (journey) resulted in a 14.6% complication rate in a study of 226 primary TKAs with a 3.5-year followup.[19] Luyckx *et al*. reported that the major causes of revision surgery in BCS-TKA were midflexion instability and friction of the illiotibial band.[22] They also stressed that to perform successful BCS-TKA, experience and surgical skill are essential for surgeons. Given the relatively high rate of complications in the journey BCS-TKA, the design was modified in the journey II BCS-TKA to reduce femoral rollback and illotibial band strain in the ROM.[8] To the best of our knowledge, no study has attempted to evaluate the mid and long term clinical results of the journey II BCS-TKA.

Recently, Takubo *et al*. reported the comparison of muscle recovery after BCS and PS-TKA. In their study, no significant difference in muscle recovery was observed between the two designs.[13] Moreover, Iriuchishima and Ryu evaluated femoral rollback in BCS-TKA compared with ACL and PCL retaining unicompartmental knee arthroplasty and asymptomatic control knees. In their study, BCS-TKA showed the same level of femoral rollback, indicating that BCS-TKA would result in normal ACL and PCL function.[10] As previously reported, the knee biomechanics of patients following TKA are different from normal knees during stair use.[9,23] McClelland *et al*. reported that fewer TKA patients were able to ascend (65%) or descend stairs (53%) unassisted compared with control patients (83%).[18] Hamai *et al*. reported that paradoxical femoral sliding was observed in mild knee flexion in CR-TKA patients.[9] In this study, postoperative stair climbing ability was significantly better in BCS-TKA patients than in CR or PS-TKA patients. Considering that the design of BCS-TKA reproduces ACL and PCL function, it is likely that the restoration of native knee function can be attained to a high degree. As Kaneko *et al*. reported that the soft-tissue balancing and stability of the knee improved during ROM following BCS-TKA,[17] resulting in better stair climbing ability. On the other hand, in the present study, stair descent ability in BCS-TKA showed no significant difference when compared with CR or PS-TKA. Compared with stair climbing motion, stair descent motion is a relatively difficult movement, which may account for the absence of statistical difference.

No statistical differences among the necessity of handrail classifications were detected in this study. In previous clinical evaluations, knee function score or international knee documentation committee score, and/or stair useability was evaluated with the number of steps at a time, pain, and the necessity of a handrail.[24] At our institution, for safety purposes, the use of a handrail is recommended for all participants even following surgery. Therefore, to avoid bias, this study separately evaluated the number of steps at a time and the necessity of handrail.

The limitations of this study were (1) small sample size with a short term followup. Longer followup is needed in the future plans. (2) Participants were not randomized. In the term of the BCS and PS-TKAs were performed, those designs TKA were randomly selected. However, in the term when CR-TKA was performed, only in the cases those visibly healthy PCL was existed, CR-TKA were performed. Randomized control trials might better reveal potential differences in clinical results. (3) Participants undergoing unilateral and bilateral surgery were included. Although the results among bilateral cases showed no differences compared to the results among unilateral cases, stair useability differs between unilateral and bilateral patients, unilateral and bilateral cases should be evaluated separately in future studies. (4) The classification of stair useability which used in this study was a newly investigated method. Although we believe that method could simply evaluate the stair useability, the accuracy and reproducibility should be evaluated for the larger sample size in the future plans.

Conclusion

BCS-TKA resulted in significantly better stair climbing ability when compared with CR or PS-TKA. This may indicate that the design of BCS-TKA better reproduces

native ACL and PCL function and improves knee stability during stair climbing activity.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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