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Journal of Orthopaedic Surgery

Journal of Orthopaedic Surgery
29(3) 1–7
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DOI: 10.1177/23094990211061610
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Does posterior cruciate ligament sacrifice influence dynamic balance after total knee arthroplasty? Comparison of cruciate-retaining and cruciate-substituting designs in bilaterally operated patients

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Abstract

Purpose: This study aimed to evaluate whether the posterior cruciate ligament sacrifice during total knee arthroplasty (TKA) has any effect on postoperative standing balance or not.

Methods: The patients who underwent bilateral TKA with either CR or PS design were analyzed. 30 patients (10 PS, 20 CR) were included for the final analysis. TKA designs were compared in terms of Lysholm score, range of motion, and balance characteristics including somatosensorial, vestibular, and visual balance scales, adaptation, limits of stability, and weight-bearing/squat tests by computerized dynamic posturography.

Results: The mean follow-up time was 59 months for CR, 49 months for PS group. The average Lysholm score values were 94 for CR and 95 for PS group, indicating functionally similar patient groups. The average knee flexion was found significantly higher in PS group (114°) compared to CR group (102°) ($p = 0.009$). In the CR group, motor adaptation tests (toes up/toes down) were found to be better ($p = 0.034$). In the on-axis velocity parameter (linear goal orientation) of limits of stability test, PS group patients were found to be more successful ($p = 0.035$).

Conclusions: The use of CR implants can be recommended in patients with a high risk of falling since they provide better motor adaptation providing rapid reactions to rapid surface changes. Better linear goal orientation in PS group, providing a faster movement in an intended direction, should be considered when planning the ideal implant for the patients with relevant activities.

Keywords

posturography, balance, dynamic, total knee arthroplasty, cruciate-retaining, cruciate-substituting, level of evidence: level III, comparative study

Date received: 15 June 2021; Received revised 26 September 2021; accepted: 26 September 2021

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Introduction

The selection of the implant type in total knee arthroplasty (TKA) can differ according to the surgeon's preference but mostly depends on the leg alignment, the severity of deformity, the range of motion, and instability. The most commonly used conventional designs are cruciate-retaining (CR) and cruciate-substituting (PS) designs. However, the literature does not support the superiority of either design in terms of implant survival and functional outcome.[1]

Balance is defined as the ability to maintain the center-of-gravity (COG) of an object within its base-of-support (BOS).[2] Cruciate ligaments are not only a mechanical structure for knee joint stability but also play an important role as a source of sensory information that could be used in the control of standing posture.[3] They provide neural feedback for the position in space with mechanoreceptors and are critical for three-dimensional interaction. Therefore, it can be assumed that the fate of the posterior cruciate in TKA can also affect the balance of the patients. The negative effects of cruciate ligament deficiency on standing balance were reported in the literature.[4] Although numerous reports are comparing these different designs in terms of clinical results, range of motion (RoM), and gait characteristics,[5,6] the effect of cruciate substituting on the balance after TKA is not clearly defined.

The advancement of technology provided better and more objective ways to evaluate and compare the effect of different pathologies or implant types on gait or postural stability.[7] The Computerized Dynamic Posturography is a method of assessing the individual's dynamic balance using different test positions arranged similarly to conditions that may be encountered in daily life. It assesses the individual's ability to use information from visual, vestibular, and somatosensory systems or ability to coordinate information received from these systems. Dynamic posturography is performed on moving platforms, in contrast to static posturography which uses stationary platforms to probe balance. Therefore, dynamic posturography can provide more sensitive information compared to static posturography.[8] It is also being used to compare the effect of different surgical techniques or implants on standing posture and dynamic balance.[9–11] This study aimed to answer these questions; "Does PS design adversely affect the dynamic balance parameters of the patients?" and "Does TKA design has any impact on different parameters of the dynamic balance?" We hypothesized that PS design adversely affects the dynamic balance parameters due to the loss of PCL.

Material and Methods

The patients who underwent staged or simultaneous bilateral TKA with CR and PS designs between 2006 and 2013 due to primary Grade IV knee osteoarthritis were analyzed. Only the patients with bilateral knee replacement were included since unilateral knee replacement can be compensated by the contralateral healthy knee.[12] A standard cemented condylar prosthesis with a fixed platform (Vanguard, Zimmer Biomet, Warsaw, Indiana) including CR (20 patients) and PS (10 patients) designs was used depending on the surgeon's preference and patient characteristics. PS design differs from CR with a rectangular bone block removal from the intercondylar area. The polyethylene insert of PS design also differs from CR with a post. The surgeries were performed by two experienced arthroplasty surgeons from the same institution. The main approach of the surgeons was to use CR design in general and to prefer PS design in the case of severe varus or flexion contracture. Gap balancing technique was used in all patients to achieve correct alignment. All patients received similar rehabilitation program which includes weightbearing in the first operative day and isometric muscle strengthening and range of motion exercises in the first 6–8 weeks. All patients provided informed consent to be included in the study, and the study was approved by the local Ethical Committee.

The clinical outcome was assessed by Lysholm score which classifies patients as excellent (95–100 points), good (84–94 points), fair (65–83 points), or poor (less than 65 points).[13] The knee RoM was measured with the help of a goniometer. Inclusion criteria were at least 2 years of follow-up (based on second TKA surgery in staged patients), no sign of knee instability, no implant loosening or implant wear, full extension and flexion ≥ 90 of the knee, and Lysholm score>65. Exclusion criteria were systemic diseases, previous knee or hip surgery, additional musculoskeletal, vestibular, or neurological disorders which can affect the balance, different TKA design in the contralateral knee, patellar resurfacing, previous patellectomy, and preoperative posterior cruciate ligament rupture.

Power analysis was performed with 1:2 allocation ratio since the number of CR patients was almost twice of the number of PS patients. Power analysis revealed that minimum of 24 patients were required with a 1:2 allocation ratio at a significance level $\alpha = 0.05$ and power = 0.8, based on data from a previous study using the difference in limits of stability values.[10] A total of 30 patients (10 PS and 20 CR) were included for the final analysis. The effect size was found to be 0.77.

Somatosensorial, vestibular, and visual balance scales, limits of stability, and motor adaptation tests were evaluated with Computerized Dynamic Posturography.

Computerized Dynamic Posturography

The following tests were performed on individuals using Neurocom Smart Balance Master (Natus Medical Incorporated, Pleasanton, CA, USA) posturography equipment

(Figure 1); Sensory Organization Test (SOT), Adaptation Test, and Limits of Stability.

Before the test, the patients were informed about the process. The patients were secured by wearing a special vest to eliminate the risk of falling (Figure 1). The tests were performed on the movable platform without shoes and socks. The tests were carried out in the order presented below.

Sensory Organization Test (SOT). The subject was instructed to maintain its balance as best as possible throughout the test. Six different conditions had been repeated three times with a duration of 60 seconds.

The test was applied according to the following procedure [14]:

1) Eyes open, and the visual surround and the platform are fixed. (Baseline measurement)
2) Eyes closed; both the visual surround and the platform are fixed.
3) Eyes open, the platform is fixed, and the visual surround is mobile.
4) Eyes open, the platform is mobile, and the visual surround is fixed.
5) Eyes closed, the platform is mobile, and the visual surround is fixed.
6) Eyes open; both the platform and the visual surround were mobile.

Equilibrium Score was calculated based on a subject's sway in which a score of 100 represents no sway, while 0 indicates sway which results in a loss of balance and requires a step. The subject's ability to use and coordinate the inputs to maintain balance was classified as somatosensory, visual, or vestibular. The values were calculated by dividing the values of conditions 2, 4, or 5 by condition 1, respectively. A composite equilibrium score was calculated using the values of six different conditions.[15]

Adaptation Test. Before the test, the patients were informed that the platform was mobile and would tilt forward and backward during the test. The subjects were asked to maintain the best possible balance throughout the test. A vest connected to the device was worn by the patients to eliminate the risk of falling. The response time to suppress external disturbance was measured to obtain toes up and toes down values (mSec). Lower values indicate a faster response.

Limits of Stability. The limits of stability test analyzed shifting the weight to eight different target positions to evaluate on-axis velocity and directional control. The target



Figure 1. The example of patient positioning on the Computerized Dynamic Posturography (Neurocom Smart Balance Master, Natus Medical Incorporated, Pleasanton, CA) (These photos were taken for the simulation of the process. In the routine procedure, the patients were tested without socks).

positions were arranged in an ellipse on the monitor screen. Limits of stability determine the maximum distance of movement in a direction without losing balance. On-axis velocity shows the speed of center of gravity movement in the intended direction. It is the average speed in degrees per second quantified for 5% – 95% of the distance from the center of the initial position.[16] The directional control determines all center of gravity movements and presented as a percentage (%). It compares the movement of the subject in the intended direction to the amount of extraneous movement away from the target.

Statistical analysis

The groups were compared in terms of age, height, weight, follow-up times, Lysholm score, RoM, and balance characteristics including somatosensorial, vestibular, and visual balance scales, motor adaptation, and limits of stability test. Descriptive statistics were used to calculate the mean and standard deviation values. Due to the small number of patients, the Mann–Whitney U test was used to compare the mean values. Correlations were calculated with the Spearman test. Statistical significance was set at $p < 0.05$.

Results

The mean follow-up time was 59.2 months (± 19.7, 33–96 months) for CR, 49.4 months (± 20.2, 30–84 months) for PS group. PS group included 10 females while CR group included 19 females and one male. No statistical difference was determined between the groups in terms of age, height, weight, surgical timing, and follow-up times (Table 1). Eight out of 20 CR and 3 out of 10 PS patients were operated in two stages, while the rest received simultaneous bilateral TKA. The time interval between two surgeries in staged patients ranged between 6 months and 2 years. The average flexion was significantly higher in PS group (114°, ±10.7, 100°–130°) compared to CR group (102°, ±10.7, 90°–120°) (p=0.009). The average Lysholm score was similar between the groups (CR:94.3, ±10.1, 72–100); PS:95.2, ±7.3, 76–100) (Table 1).

There was no statistically significant difference between the groups in general static and dynamic evaluations performed on somatosensory, visual, and vestibular scales including composite equilibrium score. There was no difficulty in terms of maintaining the center of gravity in both groups. In the CR group, motor adaptation tests (toes up/toes down) were found to be significantly better compared to the PS group (p= 0.034). In the limits of stability test, when on-axis velocity was evaluated, PS group patients were found to be significantly more successful compared to the CR group (p=0.035) indicating a better linear goal orientation. However, the directional control parameter did not yield a significant difference (Table 2). No correlation between Lysholm scores and balance parameters was detected.

Discussion

The CR design provided better motor adaptation with rapid reaction to rapid surface changes. However, the PS design provided a better on-axis velocity indicating a faster movement in an intended direction compared to the CR design in bilaterally operated TKA patients.

The literature does not have any clear evidence about the superiority of any TKA designs in terms of clinical outcome.[1] Also, the gait analysis studies did not yield an important difference.[6,17] Joglekar et al. could not show any difference in gait parameters between CR and PS designs.[6] Hajduk et al. also determined no gait kinematic differences between CR and PS designs in a gait analysis study of 41 patient.[17] However, Victor et al. analyzed 44 patients and determined greater and more consistent tibiofemoral rollback in PS patients compared to CR.[18] There are conflicting reports about postoperative RoM of CR and PS designs. Although some studies reported no difference,[19] there are also some reports reporting better flexion values in patients with PS design due to the sacrifice of PCL which prevents a possible limitation in flexion due to PCL tightness.[1,20,21] Our results also pointed out better flexion values in patients with PS design.

There are several studies analyzing patients with TKA in terms of balance characteristics. Bakirhan et al. compared

Table 1. Demographic characteristics of the patients according to the groups.

	CR (mean ± SD, range)	PS (mean ± SD, range)	p- value
Age	72.6 (± 7.7, 64–82)	68.1 (± 5.4, 60–81)	0.11
Gender	19 F, 1 M	10 F	0.75
Bilateral TKA timing	12 simultaneous, 8 staged	7 simultaneous, 3 staged	0.59
Follow-up (months)	59.2 (± 19.7, 33–96)	49.4 (± 20.2, 30–84)	0.29
Lysholm	94.3, (±10.1, 72–100)	95.2 (± 7.3, 76–100)	0.64
Flexion	102° (± 10.7, 90°–120°)	114° (± 10.7, 100°–130°)	0.009*

p<0.05; CR, cruciate-retaining; PS, cruciate-substituting; F,female; M,male.

Table 2. The comparison of balance characteristics according to the groups. Higher score indicates increased stability.

			CR (mean±SD.)	PS (mean±SD)	*p*-value
Sensory organization (%)		**Somatosensorial**	73.8 (± 22.1)	71.2 (± 19.4)	0.507
		Visual	96.1 (± 28.2)	98.2 (± 26.6)	0.551
		Vestibular	91.2 (± 26.3)	89.3 (± 24.6)	0.686
Composite equilibrium score (%)			72.9 (± 18.1)	70 (± 18.8)	0.422
Adaptation (mSec)		**Toes up**	51.6 (± 12.5)	66.7 (± 14.5)	0.034*
		Toes down	47.8 (± 17.4)	52.7 (± 11.3)	0.155
Limits of stability	**Left/Right**	**On-axis velocity (deg/sec)**	6.1 (± 3.2)	9.3 (± 4.1)	0.047*
		Directional control (%)	82.9 (± 26.9)	85.1 (± 23.4)	0.331
	Front/Back	**On-axis velocity (deg/sec)**	2.1 (± 1.1)	4.3 (± 1.6)	0.035*
		Directional control (%)	46.7 (± 12.9)	53.2 (± 15.4)	0.105

$p<0.05$; CR, cruciate-retaining; PS, cruciate-substituting.

unilateral and bilateral TKA patients operated with CR design at 6th and 12th months.[10] They found similar static balance parameters including the modified clinical test of sensory interaction on balance and unilateral stance. However, bilateral patients performed better in the limit of stability evaluations suggesting better dynamic balance. Rhythmic weight shift, which is also a component of dynamic balance, did not show a significant difference. Bascuas et al. also analyzed the static balance parameters of TKA patients at the preoperative period and postoperative first year including both unilateral and bilateral patients and also both CR and PS designs.[22] They found no difference neither between CR and PS nor unilateral and bilateral patients. However, their patient group included only six bilateral patients. Although they achieved improvement in static balance parameters at first year compared to the preoperative period, they found no correlation between balance parameters and clinical score, similar to our study.

Isyar et al. analyzed the effect of TKA design on balance parameters similar to our study.[23] However, they only included unilateral patients, in contrast to our study which included only bilateral patients. They found better results with PS design only in anteroposterior stability index suggesting better dynamic stability at average 25 months follow-up. In a prospective randomized study, Swanik et al. analyzed the effect of TKA design on balance parameters and could not show any advantage of preserving posterior cruciate ligament on proprioception and dynamic balance.[24] However, they analyzed only the patients with a unilateral TKA. In addition, they evaluated the patients at an earlier postoperative period (sixth month) compared to our study which included the patients with at least 2 years of follow-up. Götz et al. also compared CR and PS designs and could not show any negative influence of PS design on postural static stability.[25] Similar to Swanik et al., they also analyzed only the patients with a unilateral TKA, and their evaluation did not include any dynamic parameter. The mean follow-up of their patients was only 5.3 months.

The toes up test (dorsiflexion of the ankle with toe) is an important parameter for dynamic balance. The inability to raise the toe during flat walking can lead to falls, especially in older ages.[11] The most common injury mechanism in the geriatric population is falling, which constitutes more than 75% of the injuries.[26] In a systematic analysis of 13 studies, Moutzouri et al. reported that TKA can increase balance, decrease the falling rates, and is effective in changing preoperative fallers to postoperative non-fallers.[27] However, they did not make any analysis of the difference between different TKA designs. In our study, CR group was found more successful in the toes up test. Therefore, activities like walking and stair climbing that are related to the mobility of the ankle and raising the toe, which are also important to prevent falls in elderly patients ,[11] can be performed more easily when posterior cruciate was preserved. The mechanical basis of this result might be the protected proprioception in patients with retained PCL.[28] Borah et al. reported that on-axis velocity diminishes with age and the older people experience difficulties to move in an intended direction, especially in seventh decade.[2] In our study, the PS group performed better in the on-axis velocity test indicating better linear goal orientation compared to the CR group. CR design can limit the ability of target orientation and reaching the target at the exact point. The mechanical reason behind this situation might be the increased flexion capability of PS designs.[1,21]

This study is not without limitations. Retrospective design and the low number of patients are the main limitations. The lack of preoperative evaluation of balance also prevented us from comparing the postoperative values to the preoperative period. Besides, the PS design was mostly preferred in the case of severe varus or flexion contracture, which can lead to worse preoperative functional capacity in the PS group. However, since the functional outcome was similar between the groups, this possible difference was compensated. A large range of follow-up duration could have also affected the results

since the postural dynamics can improve throughout the time. Gap balancing technique was used to achieve correct tensions of ligaments, but it was not possible to confirm that the soft tissue components were standardized in all patients. Less than 90 degrees of knee flexion was an exclusion criterion since some tasks in CDP require 90 degrees of flexion. This exclusion criterion might have compromised our results regarding flexion values which indicated less flexion capacity in CR group. Finally, with further validation studies, it is also required to analyze whether the results obtained from this study transform into clinical significance and affect the daily activities of a patient. To the best of our knowledge, this is the first study comparing PS and CR designs in patients with bilateral TKA, in terms of balance characteristics.

Conclusions

This study determined that CR and PS designs can have different effects on postural stability when applied bilaterally. CR design may provide better motor adaptation (especially in walking dynamics) reducing the fall risk while PS design may provide better linear goal (an object, heading to the target, etc.,) orientation with a faster movement in an intended direction. Implant design should be chosen both according to the stage of the disease and the potential postural/dynamic balance expectations of the patients. The hypothesis of this study—which was; PS design adversely affects the dynamic balance parameters due to the loss of PCL—was partially supported by the results of motor adaptation test. However, the results of limits of stability test also revealed that PS design has its own advantages too. This study provides preliminary biomechanical findings. Further studies should be conducted to truly understand the effect of knee implant on balance and to verify the findings of this study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Ethical approval

The ethical approval was obtained from institutional review board of the authors' affiliated institution.

Informed consent

Written informed consent was obtained from all patients.

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