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Brief communication

The effect of constraint on post damage in total knee arthroplasty: posterior stabilized vs posterior stabilized constrained inserts

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A B S T R A C T

Posterior stabilized constrained (PSC) inserts are intended to provide greater varus-valgus and rotational constraint than conventional PS inserts. We determined whether the added constraint resulted in more damage to the post in PSC compared to PS inserts. Retrieved PSC inserts were matched to retrieved PS inserts from the same manufacturer according to patient age, body mass index, and length of implantation. Surface damage was visually assessed, and 3-D surface deviation from pristine was measured. Damage scores for the PSC posts were significantly greater than those of the PS posts. Surface deviation was significantly greater in the posterior and medial post regions of the PSC inserts. Based on short-term follow-up, our results suggest that added constraint is accompanied by greater polyethylene surface damage.

Introduction

The goal of total knee arthroplasty (TKA) is to obtain a well-balanced flexion-extension gap with balanced collateral ligaments. Large angular deformities, bone loss, ligamentous contracture or instability, or inability to achieve a balanced flexion and extension gap in spite of appropriate balancing techniques can warrant the use of increased constraint in primary TKA [1]. Increased constraint can be achieved with a constrained condylar knee (CCK) system by using a wider polyethylene post that closely conforms to a large femoral component box. Increased stability is achieved by limiting varus-valgus and torsional movement, the extent of which varies across different designs [2,3]. A concern with the use of CCK designs is that such a high degree of post-box constraint can impart additional loads on the bone-implant interface. Although stem extensions can mitigate this concern by distributing load to the diaphysis [4], stems are invasive, increase implant cost, increase the complexity of surgery, and are associated with leg and thigh pain [5-7].

An intermediate solution to this dilemma is a posterior stabilized constrained (PSC) insert. Such inserts have a wider post than a standard posterior stabilized (PS) insert, but a narrower and shorter post than a CCK insert, thus conforming to standard PS femoral boxes (Fig. 1). The amount of constraint varies by design; one such insert, the Optetrak Logic PSC (Exactech, Gainesville, FL), provides 3° of varus-valgus motion and 4° of rotational motion before post-box contact, as compared to the CCK insert from the same manufacturer that provides only 1.5° of varus-valgus motion and 2° of rotational motion [8]. A standard PS insert offers no varus-valgus and limited rotational constraint.

Previous research showed that increased constraint leads to increased polyethylene wear, which in turn is associated with osteolysis and component loosening [9-12]. Wear damage in PS inserts is most severe on the posterior surfaces of the post due to interaction with the cam, whereas CCK designs experience greater medial and lateral post wear damage [13]. Likewise, a recent retrieval analysis by Pang et al [14] of 18 varus-valgus constrained Genesis II inserts (Smith & Nephew, Memphis, TN) demonstrated increased overall post wear when compared to matched Genesis II PS designs. However, the extent of wear in PSC polyethylene inserts

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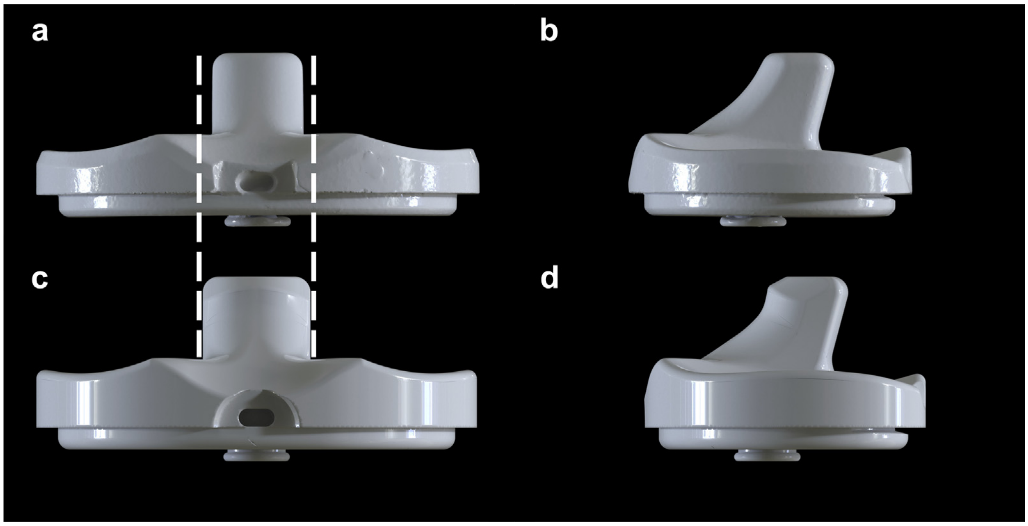

Figure 1. 3-D image demonstrating differences in the widths of the posts between the PS insert (shown in views a and b) and the PSC insert (shown in views c and d).

has yet to be examined. We therefore designed a match-paired analysis of polyethylene inserts retrieved during revision TKA to determine the extent of additional post wear in PSC inserts when compared to PS inserts.

Material and methods

Thirty-six Optetrack Logic PSC tibial inserts were collected during revision TKAs that were performed at our institution from March 2013 to April 2016 as part of our ongoing institutional review board—approved implant retrieval program. These inserts were matched to Optetrack Logic PS tibial inserts that had been previously retrieved. Matching was performed on the basis of patient sex, age, body mass index (BMI), and the length of implantation. Due to the limited number of retrieved PSC inserts, we were unable to match on the basis of insert size or thickness. Demographic data were obtained from clinical records, and the indication for revision surgery was determined from operative notes (Table 1).

Radiographic assessment

Initial postoperative weight-bearing anteroposterior and lateral digital radiographs were reviewed to assess component alignment. Measurements were made using methods described by Meneghini et al [15]. The position of the femoral component was measured with respect to a 5° valgus cut angle. Tibial components were measured in relation to a perpendicular tibial cut. Valgus component alignment was expressed as a positive value, and varus component alignment was expressed as a negative value. Lateral images were assessed for femoral component flexion with respect to the intramedullary axis and for tibial component posterior slope.

Visual damage assessment

To visually assess surface damage to the polyethylene inserts, well-established subjective methods were used to assign damage scores [16]. The articulating surfaces of the inserts were divided into 14 regions, and the backside of the inserts was divided into 4 regions (Fig. 2). Two independent observers (JK, LW), blinded to the clinical, demographic, and radiographic data, visually inspected each region under stereo light microscopy at 10× magnification. Each region was assessed for 7 damage modes: scratching, pitting, burnishing, abrasion, delamination, surface deformation, and third-body debris. Damage sustained during surgical removal was disregarded. Each damage mode was assigned a score of 0 to 3 based on the severity and extent of the damage. This gave a maximum possible damage score of 378 (294 for the articular surface and 84 for the backside). The difference in total damage scores was never greater than 10 points between the 2 observers; therefore, a third observer was not used. The mean value among observers was used for analysis.

Surface dimensional changes

Surface dimensional changes were quantified using a laser scanning method described by Stoner et al [17]. This method determines the dimensional changes in the surface geometry of the inserts compared either to the design drawing for the part or to a pristine insert of the same size as the retrieved insert. The dimensional changes likely resulted from both permanent deformation of the insert and loss of material (wear).

The 36 matched pairs of inserts were coated with aerosol talc and scanned using a 3-D laser scanner (Range 7; Konica Minolta, Inc., Tokyo, Japan). To obtain a scan of the complete surface of each insert, 20 scans at different viewing angles were performed. The data analysis was performed using Geomagic Studio software (Morrisville, MC).

Reconstructed 3-D models were precisely aligned with either manufacturer-provided computer-aided design (CAD) models

Table 1
Patient demographic data.

Variable	PSC insert	PS insert	*P* value
Number	36	36	N/A
Percentage of females	52.5%	40.0%	.19
Age at index surgery (y)	66.1 ± 6.8	63.7 ± 7.7	.13
Body mass index (kg/m^2)	30 ± 6.8	29.7 ± 5.2	.72
Length of implantation (mo)	11.2 ± 10.4	13.9 ± 9.4	.13

N/A, not applicable.
Data are presented as mean ± standard deviation; comparisons were made using Student *t*-tests for continuous variables and chi-square tests for categorical variables.

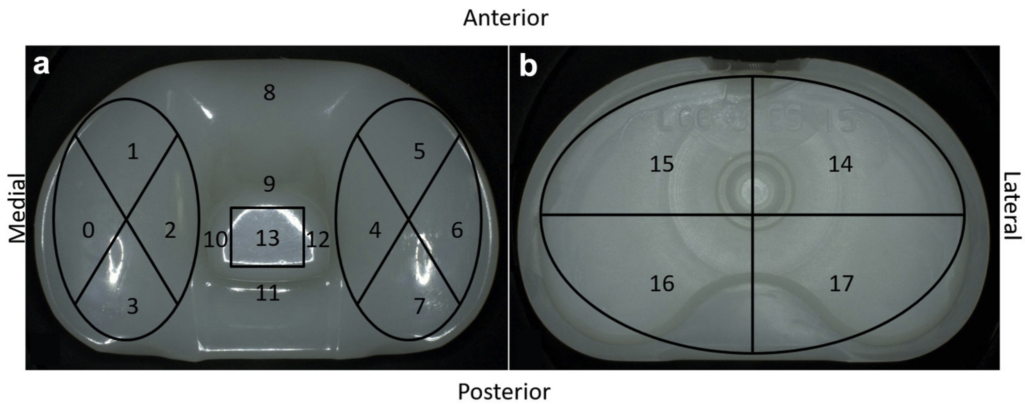

Figure 2. The insert articular surface (a) was divided into 14 regions. Regions 0-7 were considered articular surface whereas regions 9-13 were considered the post. The insert backside was divided into 4 regions (b). Orientation is labeled for the articular surface view (a).

(PSC) or scans of pristine, never-implanted inserts (PS). The average distances between the surfaces of the pristine or CAD model and the retrieved insert model were measured between the closest points in each model. Additionally, because both positive and negative deviations were present, we used the root mean square of the distance (RMSd) between the pristine insert or the CAD model and the retrieved model to obtain an overall measurement of surface deviation:

$$\mathrm{RMSd} = \sqrt{\frac{\sum_i d_i^2}{n}}$$

In the above equation, d is the distance between the n pairs of closest points between the surfaces of the models.

Statistical analysis

For matching PSC and PS inserts, statistical comparisons were made using paired Student *t*-tests for patient age, BMI, and length of implantation; patient sex was compared using a chi-square test. Radiographic alignment variables, polyethylene damage scores, and differences in RMSd were compared using paired Student *t*-tests. Multivariate regression analysis was performed to determine the correlations among demographic data (age, BMI, gender), length of implantation, and implant alignment to polyethylene damage scores.

Results

The mean patient BMI across the 2 matched groups was 29.8 ± 6.1 kg/m^2, mean age was 64.8 ± 8.0 years, and average length of implantation was 11.2 ± 10.4 months for the retrieved PSC inserts and 13.9 ± 9.4 months for the matched PS inserts (Table 1). There were 52.5% females in the PSC group and 40% females in the PS group (P = .19). Post-primary TKA alignment (Table 2) demonstrated slight femoral component valgus with respect to the femoral mechanical axis for both the PSC cohort (0.5° ± 3.7°) and PS cohort (0.8° ± 2.7°), and slight tibial component varus with respect to the tibial mechanical axis for both cohorts (1.1° ± 2.3° vs 1.5° ± 2.5°). The most common indications for revision (Table 3) were infection (39% of PSC inserts vs 31% of PS inserts), aseptic loosening (22% PSC vs 8% PS), stiffness (14% PSC vs 17% PS), and instability (11% PSC vs 25% PS). No significant differences existed in the sex, age, BMI, length of implantation, radiographic alignment, or indications for revision between the PSC and PS inserts.

The highest scores for damage to the polyethylene articulating surfaces were observed for scratching, pitting, and abrasion in both sets of inserts (Table 4). Total damage scores within the articular regions (regions 1-7) were similar between the PSC inserts and PS inserts (29.4 ± 12.4 vs 27.7 ± 7.2, P = .50). Higher total damage scores occurred within the post region of the PSC inserts than the PS inserts (12.0 ± 5.3 vs 7.0 ± 3.0, P < .0001). Less average backside damage (regions 14-17) was found when compared to other regions, and no significant difference occurred between backside damage of PSC and PS inserts (1.4 ± 2.0 vs 0.8 ± 1.2, P = .12).

No differences were found in 3-D surface deviations (Fig. 3) in the articular regions of the PSC inserts compared with the articular regions of the PS inserts, with a root mean square deviation of 0.27 ± 0.12 mm in the PSC inserts vs 0.23 ± 0.09 mm in PS inserts (P = .12). When comparing the post regions, a greater RMSd was found in the posterior post region (0.42 ± 0.13 mm vs 0.31 ± 0.16 mm, P = .01) and medial post region (0.35 ± 0.12 mm vs 0.27 ± 0.13 mm, P = .03) of the PSC inserts. However, no difference was found in RMSd in the anterior (0.29 ± 0.13 mm vs 0.24 ± 0.13 mm, P = .18) or lateral post regions (0.35 ± 0.11 mm vs 0.34 ± 0.24 mm, P = .84).

Multivariate regression indicated no significant relationships between sex, BMI, age at index surgery, or length of implantation. However, implant type (PSC vs PS) was significantly correlated to

Table 2
Radiographic alignment.

Variable	PSC inserts	PS inserts	*P* value
Femoral component valgus[a]	0.5 ± 3.7	0.8 ± 2.7	.67
Tibial component valgus	−1.1 ± 2.3	−1.5 ± 2.5	.49
Femoral component flexion	4.1 ± 3.9	3.2 ± 3.7	.40
Tibial component posterior slope	5.5 ± 3.7	4.1 ± 3.2	.11

Data are presented as mean ± standard deviation; comparisons were made using paired Student *t*-tests for continuous variables and chi-square tests for categorical variables.
[a] Measured with respect to anticipated 5° valgus cut angle.

Table 3
Indications for revision.

Indication	PSC liners	PS liners	Total	*P* value
Aseptic loosening	8 (22%)	3 (8%)	11 (15%)	.13
Infection	14 (39%)	11 (31%)	25 (35%)	.55
Instability	4 (11%)	9 (25%)	13 (18%)	.17
Fracture	1 (3%)	0 (0%)	1 (14%)	.32
Component malpositioning	1 (3%)	0 (0%)	1 (14%)	.32
Pain	0 (0%)	1 (3%)	1 (14%)	.32
Stiffness	5 (14%)	6 (17%)	11 (15%)	.76
Unspecified	3 (8%)	6 (16%)	9 (13%)	.32

Comparisons made using Pearson's chi-square test.

Table 4
Average damage scores by damage mode and liner region.

Damage mode score	Articular surface damage			Post damage			Total liner damage		
	PSC liners	PS liners	*P* value	PSC liners	PS liners	*P* value	PSC liners	PS liners	*P* value
Deformation	0.4 ± 0.9	0.08 ± 0.4	.038	0.4 ± 0.8	0.5 ± 0.8	.8	0.9 ± 1.5	0.6 ± 0.9	.28
Third-body debris	0.2 ± 0.7	0.3 ± 0.8	.65	0.1 ± 0.5	0 ± 0	.1	0.3 ± 1.1	0.3 ± 0.8	.81
Scratching	13.6 ± 5.8	10.4 ± 4.0	.004	4.6 ± 2.7	3.0 ± 1.7	.0006	18.6 ± 8.1	13.5 ± 4.8	.0007
Burnishing	0.3 ± 1.8	3.4 ± 4.5	.0006	0.0 ± 0.0	0.8 ± 0.5	0.32	0.4 ± 1.9	3.5 ± 4.4	.0007
Delamination	0.03 ± 0.2	0 ± 0	.32	0.03 ± 0.2	0.0 ± 0.0	.32	0.06 ± 0.2	0 ± 0	.16
Pitting	13.3 ± 5.8	12.1 ± 3.8	.39	5.0 ± 2.8	2.4 ± 1.7	<.0001	18.5 ± 8.2	14.7 ± 4.6	.029
Abrasion	1.7 ± 2.4	1.3 ± 1.7	.49	2.7 ± 1.9	1.3 ± 1.5	.0021	4.4 ± 3.2	2.6 ± 2.7	.028
Total damage score	29.4 ± 12.4	27.7 ± 7.2	.5	12.9 ± 6.1	7.2 ± 3.1	<.0001	43.3 ± 17.9	35.2 ± 8.5	.025

Data are presented as mean ± standard deviation; comparisons were made using paired Student *t*-tests. Articular surface consists of regions 0-7; post consists of regions 9-13.

both post damage score and overall damage score with the PSC inserts having higher scores. Furthermore, higher tibial component posterior slope was associated with increased tibial post damage ($P = .03$) (Table 5).

Discussion

This study compared 36 retrieved PSC inserts to 36 matched PS inserts with the goal of comparing polyethylene damage sustained in vivo to the post region. We used a well-established method for visually comparing accumulated damage in retrieved polyethylene inserts [16] and laser scanning to examine 3-D surface changes [17]. No significant differences existed between the 2 groups of inserts after matching for patient age, BMI, sex, and length of implantation, and no differences were found in radiographic component alignment, indications for revision TKA, or damage within the articular surface regions of the inserts. After accounting for these potentially confounding variables, we nonetheless noted more damage in the post regions of the more constrained PSC inserts compared to the less constrained PS inserts. Implant type (PSC vs PS) was the only variable that correlated strongly with the degree of post damage. Furthermore, this was reflected by increased surface deviation of the posterior and medial post regions as determined by 3-D scans of the inserts.

Our findings are consistent with studies that examined surface damage in PS and CCK designs. Puloski et al [13] examined the posts of 23 retrieved PS inserts using a similar visual scoring methodology as the present study. They noted post wear in every retrieved insert, which was significantly worse in the posterior regions, presumably due to the cam-post interaction. Additionally, the more constrained CCK inserts in this study exhibited more wear on the medial and lateral post surfaces than the nonconstrained designs. Pang et al [14] compared 18 retrieved Genesis II PS inserts (Smith & Nephew, Inc., Memphis, TN) with 18 retrieved Genesis II varus-valgus constrained inserts. Similar to our study, they found no differences in the articular surface damage, but did find increased wear in the posts of the varus-valgus constrained inserts when using visual scoring methods. However, in contrast to our study, Pang et al demonstrated a correlation between post damage and femoral and tibial component malposition, defined as >3° femoral valgus and >3° tibial varus or valgus. They also demonstrated more post wear when the tibial component had anterior slope. We did not find such a correlation, but we did note an association between increased tibial component flexion and post damage. However, we are unaware of any similar study that has used 3-D scanning methods to analyze surface deviation in partially constrained vs unconstrained retrieved inserts.

Our study was limited by several factors. One limitation was the relatively short length of implantation (mean 11.2 months) for the PSC inserts. This was a limitation imposed by the retrieved implants available at the time of the study. Future studies may elucidate whether a larger difference in post damage exists between PSC and PS implants with longer lengths of implantation. Second, our study was limited by the number of available inserts. While our study was larger than the studies discussed above, it may be underpowered to detect the influence of important variables such as varus or valgus femoral and tibial component position on post wear. Third, as a retrieval study, we examined inserts that have been associated with failed implants. Thus, it is possible that our results do not reflect well-functioning implants. Finally, we were unable to precisely size-match our study inserts with PS controls; this was also due to a limited availability of controls and our goal of matching patient age, sex, BMI, and length of implantation as closely as possible.

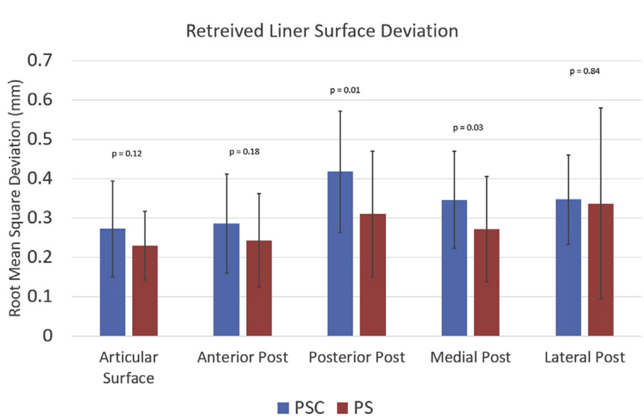

Figure 3. Surface deviations are plotted for the PSC and PS retrieved inserts. Comparisons were made using Student *t*-tests.

Conclusions

In conclusion, our short-term retrieval study demonstrates increased wear in the post region of PSC inserts when compared to

Table 5
Multivariate regression analysis.

Variable	Articular damage score	Post damage score	Total damage score
Implant type (PSC vs PS)	0.19	<0.0001	.01
Gender	0.87	0.76	.88
Body mass index	0.12	0.11	.09
Age at index surgery	0.85	0.36	.72
Length of implantation	0.08	0.19	.07
Femur component valgus	0.89	0.48	.72
Tibial component valgus	0.95	0.97	.88
Femur component flexion	0.37	0.20	.30
Tibial component posterior slope	0.49	0.03	.74
R-square	0.14	0.46	.24

Table presents the *P* value of each coefficient of multiple regression analysis.

PS inserts, corresponding to more surface deformation in posterior and medial post regions. However, the increased damage and deviation of the post surfaces was minimal and likely clinically insignificant in these short-term retrievals. Furthermore, criticizing the use of PSC implants based on increased polyethylene damage is an inappropriate conclusion to draw from our findings. Presumably the surgeons who chose to use these PSC inserts in their patients did so because of a concern for adequate stability provided by balanced ligament and a conventional PS insert. If their suspicions were correct, the PSC inserts did indeed add constraint as would demonstrated by increased surface damage and deviation as the PSC post contacted the inner edges and the cam of the femoral component. This might be reflected by the fact that more of the PSC inserts were revised for aseptic loosening (Table 3), assuming that aseptic loosening is associated with more load transferred at the component interfaces because of the increased constraint. But our study is not powered to draw such an inference. Therefore, we plan to follow up this study with longer-term retrievals as they become available to monitor any increased levels of damage that might occur.

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