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Journal Title: Arthroplasty Today

Volume: Volume 3, Number 4

Publisher: Elsevier | 2017-12-01, Pages 257-263

Type of Work: Article | Final Publisher PDF

Publisher DOI: 10.1016/j.artd.2017.05.001

Permanent URL: <https://pid.emory.edu/ark:/25593/s6rw2>

Final published version: <http://dx.doi.org/10.1016/j.artd.2017.05.001>

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Accessed December 9, 2022 1:03 AM EST



Original research

Comparison of adverse events rates and hospital cost between customized individually made implants and standard off-the-shelf implants for total knee arthroplasty

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ARTICLE INFO

Article history:

Received 6 December 2016

Received in revised form

8 March 2017

Accepted 4 May 2017

Available online 9 June 2017

Keywords:

Adverse event rate

Hospital cost

Length of stay

Customized individually made implant

TKA

ABSTRACT

Background: This study compares selected hospital outcomes between patients undergoing total knee arthroplasty (TKA) using either a customized individually made (CIM) implant or a standard off-the-shelf (OTS) implant.

Methods: A retrospective review was conducted on 248 consecutive TKA patients treated in a single institution, by the same surgeon. Patients received either CIM (126) or OTS (122) implants. Study data were collected from patients' medical record or the hospital's administrative billing record. Standard statistical methods tested for differences in selected outcome measures between the 2 study arms.

Results: Compared with the OTS implant study arm, the CIM implant study arm showed significantly lower transfusion rates (2.4% vs 11.6%; $P = .005$); a lower adverse event rate at both discharge (CIM 3.3% vs OTS 14.1%; $P = .003$) and 90 days after discharge (CIM 8.1% vs OTS 18.2%; $P = .023$); and a smaller percentage of patients were discharged to a rehabilitation or other acute care facility (4.8% vs 16.4%; $P = .003$). Total average real hospital cost for the TKA hospitalization between the 2 groups were nearly identical (CIM \$16,192 vs OTS \$16,240; $P = .913$). Finally, the risk-adjusted per patient total cost of care showed a net savings of \$913.87 ($P = .240$) per patient for the CIM-TKA group, for bundle of care including the preoperative computed tomography scan, TKA hospitalization, and discharge disposition.

Conclusions: Patients treated with a CIM implant had significantly lower transfusion rates, fewer adverse event rates, and were less likely to be discharged to a rehabilitation facility or another acute care facility. These outcomes were achieved without increasing costs.

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Introduction

Osteoarthritis (OA) of the knee generates a substantial economic burden within the US health care system [1,2]. Total knee arthroplasty (TKA) is relatively common and estimates indicate over

650,000 TKA procedures will be performed annually in the United States through 2030 [3]. TKA is associated with low mortality rates and treats OA effectively. Approximately 80%–90% of patients who undergo TKA report clinically significant improvement in pain and functional outcome [4–9]. Although an effective procedure, TKA and its associated hospital resource utilization accounted for \$3.5 billion of reimbursement from the Medicare Program in the fiscal year 2011 [10]. A portion of these expenditures are generated by the infrequent, but significant, effects of major adverse events after TKA which add substantially to hospital treatment cost (the risk-adjusted cost of treating adverse events range between \$30,900 [pneumonia] and \$2200 [hemorrhage or postoperative shock requiring transfusions]) [11].

TKA procedures primarily use implants that are off-the-shelf (OTS) devices constructed with standard fixed sizes. The use of OTS implants requires the surgeon to make adjustments to fit the

The authors do not have any proprietary interest in the material describe in this article and did not receive any grant support for this research.

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to <http://dx.doi.org/10.1016/j.artd.2017.05.001>.

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<http://dx.doi.org/10.1016/j.artd.2017.05.001>

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standard device to the biophysical needs of the patient during the procedure. The alternative to OTS devices is the use of a customized individually made (CIM) implant device anatomically designed with personalized fit, patient-matched anatomic shape, and greater bone preservation. However, there are sparse empirical data available to demonstrate the extent to which the choice of device implanted (OTS vs CIM) impacts hospital outcomes and total hospital cost after a TKA. The determination of total hospital cost associated with the implant device is growing in importance to hospitals because private third-party payers are increasingly placing the hospital at risk for the cost of all hospital services provided to TKA patients through the implementation of bundled payment for acute surgical procedures [12]. The present study retrospectively compared outcomes between patients who received an OTS device and those who received a CIM device during their TKA procedure. Specific metrics compared included length of procedure, length of hospital stay (LOS), blood transfusion rates, other selected adverse events associated with the implantation before discharge and within 90 days after discharge, and patient discharge status. Given the need for improving the cost-effectiveness of TKA procedures, a second study objective was to determine the extent to which average total real hospital costs for TKA hospitalization and total cost of care for the health insurance differed depending on the type of device implanted.

Material and methods

Study population and unit of observation

To address the study questions, we conducted a retrospective assessment of patient records from a single surgeon at one health care institution. All TKA surgeries occurred between April 1, 2010, and November 11, 2013. The intraoperative protocol was consistent over the study period: all patients received a spinal anesthesia unless they refused or were contraindicated; the surgical approach was through a medial parapatellar incision; the blood management protocol did not change; and patients received a Foley catheter overnight. The surgeon's office medical records were used to identify all patients who underwent a TKA procedure during the study period. All patients underwent their TKA procedure, including the choice of TKA device, before the start of data collection.

The unit of observation in this study was the TKA hospitalization. The final study sample included a total of 235 unique patients who underwent a total of 248 TKA hospitalizations in which the patient received either a CIM implant (126 hospitalizations) or an OTS implant (122 hospitalizations). In this study, 49 patients undergoing a simultaneous bilateral TKA procedure were considered as a single hospitalization. A patient undergoing a staged bilateral TKA was treated in the analysis as 2 separate hospitalizations because they had distinct admission dates, discharge dates, and clinical outcomes for both admissions. Review of the patient records indicated that all TKA devices inserted between April 1, 2010, and September 19, 2011, were OTS devices, after which the surgeon began to transition to the CIM implant, with continued OTS implant utilization. During the transition period (4 months), patients about to undergo a TKA were offered the choice between receiving a CIM implant or an OTS implant after a discussion of the risk-benefit profile of both systems with the surgeon. After April 2, 2012, the vast majority of TKA devices implanted were CIM implants. This analysis includes all "learning curve" cases without stratification for learning curve effects. All patients in the study who underwent 2 TKA procedures (either staged bilateral or simultaneous bilateral) received the same type of device in both procedures.

Data collection

All data collected in this study were obtained either from the surgeon's medical records or from the study hospital's Unified Billing 2004 (UB-04) form. The study manager received deidentified paper medical records for each TKA procedure performed during the study period. Each procedure's clinical record was assigned a unique study ID. Clinical data collected from the medical records were double entered into a procedure-level electronic data base by 2 independent clinical abstractors. The information was audited for accuracy by comparison with the paper medical record. In addition, the surgeon's office staff collected copies of the hospital's UB-04 bill for each study patients' TKA hospitalization and any rehospitalization a patient had in the study hospital within 90 days of hospital discharge from the study TKA hospitalization. Patients who underwent staged bilateral TKA surgeries required 2 hospitalizations with separate 90-day follow-up periods. If the second TKA procedure was performed during the original 90-day follow-up period for the first TKA procedure, the second hospitalization was not counted as a follow-up hospitalization for the original TKA procedure. All UB-04 forms included the unique study ID for the patient undergoing the procedure so that clinical information in the medical record could be matched with the hospital administrative record. Information collected from the UB-04 form (all *International Classification of Diseases, Ninth Revision, Clinical Modification [ICD-9-CM]* diagnosis and procedure codes, patient's discharge destination, and total hospital billed charges) was entered into a separate electronic database by 2 independent clinical abstractors. The information was audited for accuracy by comparison with the paper UB-04.

Definitions of demographics, hospital information, comorbidities, and adverse events

The final data set contains demographic information including each patient's gender, age at admission, American Society of Anesthesiologists Physical Status Classification System (ASA) at admission, and body mass index (BMI). Hospital LOS in days was calculated using the patient's admission date and time and their discharge date and time. In addition, the hospital's UB-04 form contained 25 diagnosis and procedure *ICD-9-CM* codes. Diagnosis codes were used to create 39 patient-level comorbid conditions (Table 1). Information contained in either the patient's medical record or the *ICD-9-CM* diagnostic or procedure codes was used to identify the following in-hospital adverse events: transfusion, any postsurgical infection, thromboembolism, and acute renal failure.

Hospital total cost

The hospital UB-04 form contained total billed charges for each hospitalization for all services provided by the hospital (the UB-04 form does not contain physician charges or charges for other nonhospital services). Total hospital costs were calculated based on the established method of estimating total hospital cost from billed charges [13,14]. Briefly, total hospital costs for each TKA hospitalization were estimated by multiplying total billed charges for each hospitalization by the appropriate annual hospital's average cost-to-charge ratio in the diagnosis-related group associated with patients undergoing TKA procedures without complications or comorbidities. Estimates of total hospital cost for TKA hospitalization that occurred before 2013 were inflated into 2013 US dollars using an index created from the study hospital's average annual cost increases in the diagnosis-related group associated with TKA procedure without complication.

Table 1
Patient baseline demographic characteristics and selected comorbid conditions for all TKA hospitalizations and by study arm.

Variables	All hospitalizations	CIM	OTS	P value
Number of hospitalizations	248	126	122	NA
Demographic characteristics				
Male, %	37.1	38.1	36.1	.793
Age, mean \pm SD, y	69.0 \pm 8.9	69.7 \pm 8.4	68.3 \pm 9.5	.226
BMI, mean \pm SD, kg/m ²	31.5 \pm 7.2	30.8 \pm 6.5	32.3 \pm 7.8	.088
Comorbidities, ^a %				
Osteoporosis	97.5	98.4	96.7	.397
Hypertension	70.1	71.5	68.6	.615
Diabetes mellitus	20.5	20.3	20.7	.948
History of smoking	18.4	13.8	23.1	.061
Chronic ischemic heart disease	11.1	12.2	9.9	.571
Prior CVA	5.7	2.4	9.1	.026
Prior total hip arthroplasty	4.1	1.6	6.6	.050
Long-term use of anticoagulation medication	5.3	2.4	8.3	.043

CVA, cerebrovascular accident; SD, standard deviation.

List of other comorbid conditions used in risk-adjusted models: malnutrition, current smoker, congestive heart failure, previous myocardial infarction, atrial fibrillation, peripheral vascular disease, inflammatory bowel disease, rheumatoid arthritis, sickle cell disease, coagulopathies, anemia, psoriasis, chronic obstructive pulmonary disease, chronic liver disease, any cancer, chronic kidney disease, nephrotic syndrome, history of hemodialysis, knee fracture present on admission, mechanical complication of prior TKA present on admission, prior TKA, prior joint arthroplasty nonspecific, prior pathologic fracture, prior traumatic fracture, prior cardiac revascularization procedure, prior liver transplant, prior kidney transplant, prior venous embolism and thrombosis, long-term use of aspirin, long-term use of antiplatelet medication, long-term use of nonsteroidal anti-inflammatory drugs, and long-term use of steroids.

^a This table only reports those comorbid conditions that were present in over 10% of all TKA hospitalizations or where there were significant differences in the proportion of patients experiencing the comorbid condition between the 2 study arms. All values in this section of the table were calculated on 244 hospitalizations because the UB04 form was missing for 4 patients (3 in the CIM arm and 1 in the OTS arm).

Total cost of care to the health insurance/payer

Increasingly, private and public third-party payers are interested in the making the total cost of all care (preoperative, inpatient care, and postdischarge care for a selected number of days) into a single payment. In this analysis, we defined total cost for a TKA bundle for every patient in both study groups as follows. First, we used only the total real cost of each TKA hospitalization collected in this study as an estimate of all TKA hospitalization cost. Second, using estimates published in the literature[13], we assigned patient-level estimates of the cost of care provided in the 30-day postdischarge period based on each patient's discharge destination from their TKA hospital as follows: home with outpatient therapy = \$733; home with home health services = \$4239; skilled nursing facility = \$6678; acute rehabilitation facility = \$16,464; and any other acute care facility was assigned the average of skilled nursing facility and rehabilitation facility = \$11,570. Third, we assigned a single cost for a computed tomography (CT) scan (\$350 per TKA) to all patients in the CIM study arm and assigned a cost for a scan (\$0 per TKA) for all patients in the OTS study arm. Finally, it was assumed that all other physician and surgeon costs were identical in the 2 study arms. We summed the first 3 costs for each patient and reported the total average cost of the episode of care by study arm.

Statistical analysis

Univariate differences in baseline demographic data and comorbidities between patients in the CIM implant arm vs the OTS implant arm were assessed with the chi-square analysis or the Fisher exact test for discrete variables and the Student *t* test for

continuous variables. Observed complication rates are reported as the proportion of hospitalizations with a selected complication of all study hospitalizations. Mean hospital LOS and mean total hospital cost for all patients and by type of TKA device are presented as mean \pm standard deviation. All regression models estimated using continuous variables were estimated using the linear form of the regression models. A step-wise multivariate approach was used to identify those comorbid conditions to include in the final risk-adjusted model for each outcome of interest. The following comorbid conditions were considered in each risk-adjusted model: smoker, history of smoking, hypertension, diabetes, chronic ischemic heart disease, prior cerebral vascular accident, atrial fibrillation, chronic kidney disease, inflammatory bowel disease, coagulopathies, rheumatoid arthritis, psoriasis, OA, any cancer, prior TKA, prior total hip arthroplasty (THA), prior coronary revascularization procedure, prior venous thromboembolism, long-term use of aspirin, long-term use of anticoagulation medication, long-term use of antiplatelet medication, and long-term use of nonsteroidal anti-inflammatory drugs. The tables of results only report comorbid conditions used in the final model for each outcome of interest. In this study, differences between study groups were considered statistically significant if the *P* value was $\leq .05$. All analyses were performed with SAS 9.3 (SAS Institute, Cary, NC).

Results

Table 1 presents patients' baseline demographics, comorbid conditions, and long-term use of medications both overall and separately for each type of TKA implant device. Males underwent TKA less frequently than females (37.1% of patients were male). The average patient age at admission for TKA was 69 \pm 8.9 years. There were no statistically significant differences in the gender or average age between patients who received the OTS or CIM implant device. Patients in the OTS study arm had higher average BMI than those in the CIM study arm (32.3 \pm 7.8 vs 30.1 \pm 6.5 kg/m²), but the difference did not reach statistical significance (*P* = .09). A larger proportion of patients in the OTS arm were assessed at an ASA level III (48.8% vs 43.9%); however, there was no statistical difference in the distribution of patients across ASA levels in the 2 study arms (*P* = .48).

Table 1 also reports on the proportion of patient experiencing comorbid conditions that were present in >10% of all patients or conditions where there was a significant difference in the proportion of patients experiencing that condition in the 2 study arms. Three of the comorbid conditions (prior cerebrovascular accident, prior THA, and long-term use of anticoagulation medication) reported significant (*P* $\leq .05$) differences in incidence between the 2 device groups. In all 3 cases, patients in the OTS study arm were more likely to experience the comorbid condition than patients in the CIM arm. Overall, the observed differences in the incidence comorbid conditions between the 2 device groups verify the need to control for difference in the underlying clinical conditions of patients undergoing THA procedures in the 2 study groups in evaluating the difference in outcomes.

Figure 1 shows the distribution of observed hospital LOS by type of device for 4 specific LOS periods. This figure indicates that compared with the OTS study arm, a greater proportion of patients in the CIM arm were discharged in <2 days or in 2-3 days and a smaller proportion of patients in the CIM arm stayed 3-4 days or ≥ 4 days. A chi-squared test for differences in the entire distribution of LOS by study arm did not reach statistical significance (*P* = .132). However, a 1-sided Fisher exact test found that a significantly greater proportion of patients in the CIM arm were being discharged from their TKA hospitalization in <3 days (<72 hours from admission to discharge) than in the OTS arm (42.1% vs 30.3%; *P* = .037).

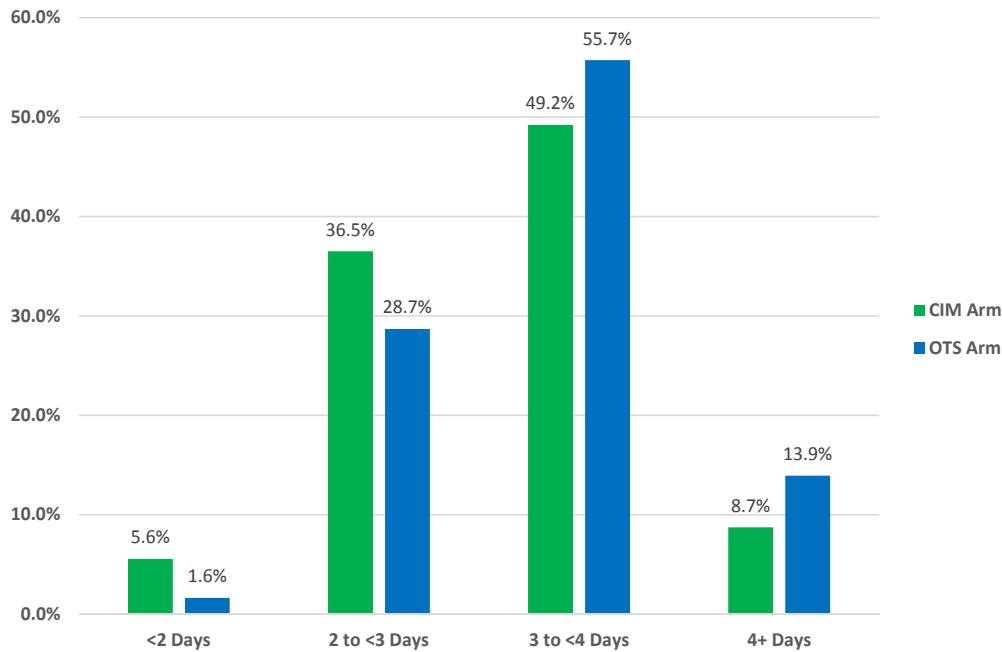


Figure 1. The distribution of observed hospital LOS by study arm for selected LOS intervals. Note: the chi-squared test of difference for the reported distribution in the figure was not significant ($P = .123$). However, a 1-sided Fisher exact test found that a significantly greater proportion of patients in the CIM arm were being discharged from their TKA hospitalization in <3 days (<72 hours from admission to discharge) than in the OTS arm (42.1% vs 30.3%; $P = .037$).

Table 2 reports the observed average hospital LOS and postoperative LOS by study arm. The table indicates that the average observed LOS for all 248 TKA hospitalizations was 3.1 ± 0.9 days. There was a trend toward shorter observed average hospital LOS among patients in the CIM arm (2.97 vs 3.20 days, approximately 5.3 hours), but did not reach statistical significance ($P = .06$). In addition, multivariate linear and log-linear regression models were estimated to determine if there were differences in hospital LOS between the 2 study arms after controlling for age, gender, BMI, and selected comorbid conditions. In all risk-adjusted models estimated, the estimated coefficient on the variable indicating that the patient was in the CIM study arm was negative, but none of the estimated coefficients in hospital LOS were significantly <0 ($P < .05$).

Figure 2 shows the distribution of discharge destination after TKA hospitalization for patients by study arm. The chi-squared statistical test indicates that there was a significant difference in the distribution of discharge destinations shown in the figure between the 2 study arms. First, it should be noted that no patient in either study arm died during their TKA hospitalization. Second, a greater proportion of patients in the CIM arm were discharged to home (9.6% CIM vs 7.4% OTS) or with home health care (62.6% CIM vs 57.0% OTS) such that approximately 71.2% of patients in the CIM arm were discharged to home or home health care compared with 63.9% of the patients in the OTS arm, but this difference did not reach statistical significance ($P = .223$). Third, **Figure 2** indicates that nearly 16.4% of the patients (20 patients) in the OTS study arm were discharged to a rehabilitation facility or another acute care

facility following their TKA hospitalization, compared with only 4.8% (6 patients) in the CIM study arm. The difference in the proportion of patients discharged to a rehabilitation facility or another acute care facility was statistically significant ($P < .01$), independent of the other discharge categories. In addition, the results of a multivariate logistical regression equation indicated that patients in the OTS study arm were $5.5\times$ (95% confidence interval $1.8\times$ – $17.2\times$) more likely to be discharged to a rehabilitation facility or other acute care facility than patients in the CIM study arm, after controlling for gender, age, BMI, and selected comorbid conditions.

Table 3 reports the observed and risk-adjusted clinical outcomes by study arm. Part A of **Table 3** reports observed in-hospital complication rates for 3 specific adverse events (transfusion, any infection, and any thromboembolism) between the 2 study arms. Overall, all 3 complication rates were relatively low, with slightly $<7.0\%$ of all patients requiring a transfusion and less than one-half of 1% of all patients experiencing the other 2 adverse events. Nevertheless, a significantly greater proportion of patients in the OTS arm required a transfusion than in the CIM arm (11.6% vs 2.4%; $P < .01$). These specific complications combined with other adverse events indicated in the medical record resulted in significantly higher rates of any adverse event for patients in the OTS arm than the CIM arm during the entire TKA hospitalization. Finally, the patients in the CIM arm had significantly lower adverse event rates from admission to 90 days postdischarge than patients in the OTS arm (8.1% vs 18.2%; $P = .023$).

Table 2

Observed average hospital LOS and average postoperative LOS for all TKA hospitalizations and by study arm.

Variables	All hospitalizations	CIM	OTS	P value ^a
Average hospital LOS (admission to discharge), d				
Hospital LOS (mean \pm SD)	3.09 ± 0.91	2.98 ± 0.94	3.20 ± 0.87	.057

SD, standard deviation.

^a The Student *t* test for differences in the continuous LOS variable. LOS in days was calculated by dividing the total number of hours between admission and discharge by 24 hours.

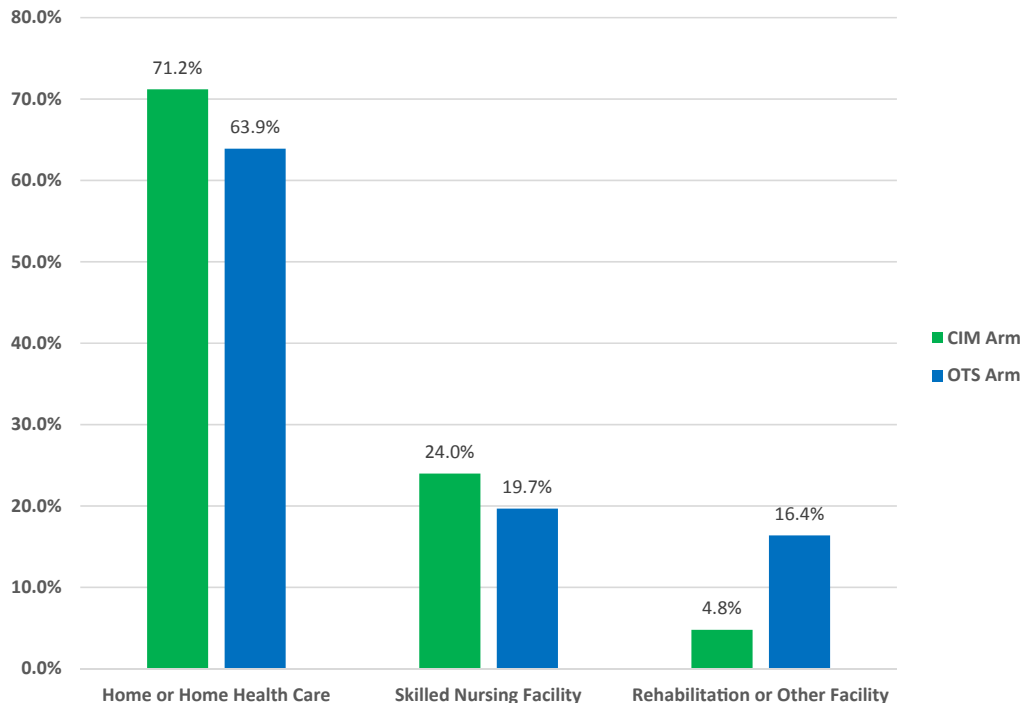


Figure 2. The discharge distribution of patients from their TKA hospitalization by study arm. The chi-squared test for differences in the discharge distribution among the 3 categories shown between the 2 study arms is statistically significant ($P = .011$). However, the chi-squared test for differences in each discharge location separately, only reached statistical significances for rehabilitation or other facilities ($P = .003$).

Part B of [Table 3](#) reports the results of the risk-adjusted multivariate logistic regression equations estimated for patients experiencing a transfusion, any adverse event during the TKA hospitalization, and any adverse event from admission to 90 days postdischarge. The key variable of interest in all regression equations was the variable indicating that the patient was in the OTS study arm. As a result, an estimated odds ratio of $>1.0\times$ implies that patients who received an OTS device were more likely to experience an adverse event than patients who received a CIM device. In addition, [Table 3](#) reports the 95% confidence interval around the estimated odds ratio of each adverse event. Results of the risk-adjusted logistic regression indicate that patients in the OTS arm were significantly more likely to require a transfusion ($4.6\times$; 95% confidence interval, $1.2\times$ - $16.9\times$) during their TKA hospitalization than patients in the CIM arm. Likewise, patients in the OTS arm were more likely to experience any adverse event during the initial hospitalization ($4.4\times$; 95% confidence interval, $1.4\times$ - $13.9\times$) and any adverse event up to 90 days postdischarge ($2.5\times$; 95% confidence interval, $1.1\times$ - $5.8\times$) than patients in the CIM study arm.

[Table 4](#), Part A, presents observed average total real hospital charges and estimated real total hospital costs both overall and for patients in each study arm. The overall average real total charges for the 244 study patients with a UB-04 bill was $\$81,461 \pm \$16,586$. Average real total hospital charges were found to be $\$2653$ more expensive in the CIM than the OTS arm, but the difference in average charges between the 2 arms did not reach statistical significance ($P = .212$). Average real total cost for all TKA hospitalizations was $\$16,216 \pm \3374 in the study. Average real hospital cost in the 2 study arms was nearly identical with cost being $\$48$ lower in the CIM arm than in the OTS arm. Part B of [Table 4](#) demonstrates that the difference in real total cost between the 2 study arms was approximately $\$92$ after controlling for differences in gender, age, BMI, and selected comorbid conditions. No significant different in estimated hospital cost between the 2 devices were found whether

the regression equation was estimated using the log-linear form of the equation or if the regression equation controlled for whether the patient underwent a bilateral or single TKA during the hospitalization (results not reported in the table).

[Table 5](#) shows real total cost of the episode of care for the OTS arm compared with the CIM arm. The observed average total cost of the episode of care for all patients in the study was $\$22,092 \pm \5940 . We found a trend toward lower observed average total costs of the episode of care in the CIM arm than the OTS arm ($\$21,591$ vs $\$22,601$; $P = .185$). Furthermore, the average cost of follow-up care in the postdischarge period was significantly low among patients in the CIM arm than the OTS arm ($\$5048$ vs $\$6361$; $P = .007$). Finally, after controlling for differences in demographics and comorbid conditions between the 2 study arms, average total cost of an episode of care was estimated to be approximately $\$913$ lower in the CIM arm than the OTS arm, but this difference was not significant ($P = .240$).

Discussion

This retrospective study of 248 consecutive TKA hospitalizations, performed by the same orthopedic surgeon, compared hospital outcomes and hospital costs for patients undergoing a CIM TKA vs an OTS TKA. Several important findings emerged from these analyses. First, CIM patients had significantly lower adverse events of any type during either the initial TKA hospitalization or during the 90 days postdischarge when compared with the patients who received OTS devices. Second, patients receiving the CIM implant had a trend toward shorter LOS than patients in the OTS study arm. Third, patients in the CIM study arm were more likely to be discharged to home or home health care and less likely to be discharged to rehabilitation or other acute care facility than patients in the OTS study arm. Fourth, compared with patients treated with OTS implants, patients treated with the CIM implant had

Table 3
Observed and risk-adjusted selected clinical outcomes for all hospitalizations by study arm.^a

Variables	All hospitalizations	CIM	OTS	P value
A: Observed selected outcomes				
Transfusion, %	6.97	2.44	11.57	.005
Any infection, %	0.41	0.00	0.83	.312
Any thromboembolism, %	0.41	0.81	0.00	.320
Any adverse event inpatient, %	8.61	3.25	14.05	.003
Any adverse event up to 90-d postdischarge	13.11	8.13	18.18	.023
B: Risk-adjusted logistic regression results for selected clinical outcomes				
Outcome variable	Transfusion	Any AE inpatient	Any AE up to 90-d postdischarge	
Odds ratio ^b	4.57×	4.37×	2.53×	
95% Confidence interval	1.2×–16.9×	1.4×–13.9×	1.1×–5.8×	
P value	.023	.013	.029	
Model c-statistic	0.762	0.799	0.687	
Final control variables:	Male gender, age, BMI, hypertension Coagulopathies, prior THA and long-term use of anticoagulation medication	Male gender, age, BMI, psoriasis, atrial fibrillation, and prior THA	Male gender, age, BMI, atrial fibrillation, prior TKA, prior THA, prior CVA, and prior revascularization procedure	

AE, adverse event; CVA, cerebrovascular accident.

^a All clinical outcomes reported in this table were based on the 244 patients with completed UB04 form.

^b All odds ratios reported indicate the odds of patients have the outcome of interest in the OTS arm relative to the CIM arm.

significantly lower observed and risk-adjusted transfusion rates. Finally, this study finds no difference in average real total hospital cost between the 2 study arms, suggesting that patients in the CIM received improved hospital outcomes at no additional cost to the hospital. However, the total cost of care to the health insurance showed a net savings of \$913.87 per patient, after including the cost of the preoperative CT scan for the CIM-TKA group.

Since the study period mentioned in this article, there is an enhanced focus on blood-management protocols, including the use of such drugs as tranexamic acid (TXA), that have shown a reduction in overall transfusion rates among TKA patients [15,16]. Tuttle et al investigated 591 patients for the incidence of transfusion and found transfusion rates dropped from 17.5% among patients without TXA to 5.5% in those who were administered TXA [17]. It is important to note that no patient in either study arm received TXA in this study. However, future clinical studies are warranted to determine if transfusion rates with the CIM implant remain lower than those using OTS implants using current blood-management protocols. Nevertheless, there remain 3 reasons why CIM implants could improve blood management. First, the femoral and tibial canals are not instrumented. Second, the bone cuts utilizing the custom implant have been shown to be thinner by 27% [18] owing to system accuracy and 6 faceted cuts, which allows for less bone resection. Third, the customized implant is designed to fit precisely over the

resected bone, leaving little to no uncovered bone where bleeding can occur after letting down the tourniquet [19].

Increasingly, private and public third-party payers are negotiating with hospitals to pay a single bundled price for all health care services associated with acute episodes of care for services like TKA [20]. Typically bundle payments include all services provided in the TKA hospitalization and all care, including readmissions, for some period, typically 30–90 days after discharge. These payment methods place increasing importance on the discharge disposition of patients undergoing a TKA. The results in Figure 2 suggest that the choice of TKA implant device results in differences in the overall discharge disposition observed in this study. If the TKA implant devices reduce discharges to high-cost postacute treatment (skilled nursing facilities and rehabilitation facilities), it could favorably impact the total cost of care during the episode that includes the postdischarge window. In fact, Table 5 estimates that suggest that after risk adjusting for differences in demographics and comorbid conditions between the 2 study arms, average total cost of the episode of care approximately \$900 less in the CIM arm than the OTS arm, even though this difference was not statistically significant ($P = .240$). This cost-saving in the CIM arm most likely underestimates the true cost-saving in an episode of care because all patients in the CIM arm were assigned a cost of \$350 for a CT scan, while none of the patients in the OTS arm were assigned any cost

Table 4
Unadjusted and risk-adjusted hospital total charge/cost for all hospitalizations and by study arm.

Variables	All hospitalizations	CIM	OTS	P value
A: Unadjusted hospital total real charges and total real cost (2013 US dollars)				
Real charges (mean ± SD)	\$81,461 ± \$16,586	\$82,777 ± \$14,254	\$80,124 ± \$18,626	.212
Real cost (mean ± SD)	\$16,216 ± \$3374	\$16,192 ± \$2758	\$16,240 ± \$3914	.913
B: Risk-adjusted estimates of total real cost using linear multivariate model^a				
Dependent variable	Estimated coefficient	P value	R2	
Total real hospital cost	+\$91.50	.833	0.14	

AMI, acute myocardial infarction; NSAID, nonsteroidal anti-inflammatory drug; SD, standard deviation.

^a Model controlled the following factors: male gender, age, BMI, diabetes, chronic ischemic heart disease, prior AMI, atrial fibrillation, inflammatory bowel disease, rheumatoid arthritis, psoriasis, any cancer, prior TKA, prior THA, long-term use of aspirin, long-term use of antiplatelet medication, and long-term use of NSAID.

Table 5
Unadjusted and risk-adjusted total cost of episode of care by study arm.

Variables	All hospitalizations	CIM	OTS	P value
A: Unadjusted total real cost of episode of care (2013 US dollars)				
Real total cost (mean ± SD)	\$22,092 ± \$5940	\$21,591 ± \$4439	\$22,601 ± \$7133	.185
Real cost follow-up care (mean ± SD)	\$5699 ± \$3829	\$5048 ± \$2929	\$6361 ± \$4482	.007
B: Risk-adjusted estimates of total real cost of episode of care using linear multivariate model ^a				
Dependent variable	Estimated coefficient	P value	R2	
Total real cost of episode	−\$913.87	.240	0.11	

AMI, acute myocardial infarction; NSAID, nonsteroidal anti-inflammatory drug; SD, standard deviation.

^a Model controlled the following factors: male gender, age, BMI, diabetes, chronic ischemic heart disease, prior AMI, atrial fibrillation, inflammatory bowel disease, rheumatoid arthritis, psoriasis, any cancer, prior TKA, prior THA, long-term use of aspirin, long-term use of antiplatelet medication, and long-term use of NSAID.

for a scan. In practice, preoperative imaging most often would be excluded from a bundled payment for TKA, irrespective of implant type.

There are several limitations to this analysis that warrant discussion. First, this analysis used a retrospective study at a single institution with a single surgeon. Care should be taken when extrapolating clinical outcome to other providers. However, it should be pointed out that the bias of the retrospective study is diminished due to the consecutive nature of patient enrollment and consistent patient management between both study arms. In addition, some of the clinical outcomes in the CIM study arm may reflect a learning curve associated with using a new implant device and outcomes, in particular, operation time may reflect the surgeons learning to use the device. A further limitation is that the study population (248 hospitalizations) limits the ability to reach statistical significance for some outcome measures. Nevertheless, nearly all the observed trends in outcomes would have reached significance with more study patients and the same observed variance in the study. A third limitation is that hospital costs were estimated from billed charges. However, this is a well-established approach to estimate costs [11,13,14], and it is unlikely that the approach used to estimate cost would consistently overestimate or underestimate the cost of treating patients in either study group. Finally, increased focus on discharge planning over the study period may explain some of the observed differences in the proportion of patients discharged to home or home health care in the CIM study arm. However, this limitation is mitigated by the fact that all patients were treated and discharged by the same surgeon.

Conclusions

Patients treated with a CIM implant had significantly lower transfusion rates and lower adverse event rates than patients treated with OTS implants. Patients treated with a CIM implant showed a trend toward a shorter LOS and a better discharge disposition than patients in the OTS arm. These improved outcomes for the CIM group were achieved without an increase in hospital costs. Future studies need to be conducted to examine the potential hospital savings associated with lower inventory management and sterilization cost-savings with the single package CIM implant.

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