

Variability in Costs Associated with Total Hip and Knee Replacement Implants

James C. Robinson, PhD, MPH, Alexis Pozen, BA, Samuel Tseng, PhD, and Kevin J. Bozic, MD, MBA

Investigation performed at the University of California, Berkeley, Berkeley, and the University of California, San Francisco, San Francisco, California

Background: Implant costs associated with total hip replacement and total knee replacement procedures account for a large share of total costs and reimbursements to hospitals. Federal policymakers are promoting episode-of-care payment and other value-based delivery and payment reforms in part to encourage physicians and hospitals to cooperate in managing costs for these and other procedures. The present study quantifies the patient, hospital, and market characteristics associated with variation in implant and total procedure costs for hip and knee arthroplasty.

Methods: Clinical, demographic, and economic data were collected on 10,155 unilateral primary total knee replacement procedures and 5013 unilateral primary total hip replacement procedures from sixty-one hospitals in 2008. Variation in implant costs per procedure was measured within and across hospitals. Multivariate statistical analyses were used to measure the association between patient and hospital characteristics and implant costs and total procedure costs.

Results: The average implant cost per case ranged from \$1797 to \$12,093 for total knee replacement procedures and from \$2392 to \$12,651 for total hip replacement procedures. For total knee replacement, 2.5% of total variation in device costs was attributable to patient characteristics and 61.0% was attributable to hospital characteristics; the remaining 36.5% of variance was attributable to within-hospital variation not due to patient or hospital characteristics. For total hip replacement, 4.4% of variance was attributed to patient characteristics, 36.1% was attributed to hospital characteristics, and 59.5% was attributed to within-hospital variation not due to patient or hospital characteristics.

Conclusions: There are substantial variations in total hip replacement and total knee replacement implant costs within and across hospitals after controlling for patient diagnoses and comorbidities. This variation is responsible for the majority of variation in the overall cost of total hip and knee replacement surgery.

Level of Evidence: Economic and decision analysis, Level III. See Instructions for Authors for a complete description of levels of evidence.

The United States health-care system is struggling to moderate growth in spending while maintaining quality-improving innovation in diagnostic and therapeutic interventions. Attention is being focused on procedures that are experiencing rapid growth in volume and cost per case,

including total joint replacement of the hip and knee, which already constitute the largest hospital expenditure category for Medicare. Procedure volumes continue to grow as the population ages and the indications are expanded to include younger, more active patients¹. Implant costs make up the largest

Disclosure: One or more of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of an aspect of this work. In addition, one or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. No author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

JBJS | Express

This article was chosen to appear electronically on August 8, 2012, in advance of publication in a regularly scheduled issue.



A commentary by Nitin B. Jain, MD, MSPH, is linked to the online version of this article at jbjs.org.

expense associated with hip and knee replacement procedures, and the average selling prices of hip and knee implants have increased >100% over the past decade². In response to these trends, both public policymakers and private purchasers are proposing or experimenting with device registries³, physician-hospital “gainsharing”⁴, bundled “episode-of-care” payment methods⁵, physician-patient “shared-decision-making” programs⁶, and other initiatives to improve quality and to reduce costs associated with total joint replacement procedures.

While many surgical procedures have migrated to the outpatient setting, total joint replacement procedures continue to be performed largely on an inpatient basis and constitute a very important component of the economic viability of many hospitals. The financial attractiveness of these procedures to hospitals depends in large part on the type and cost of the total joint replacement implants used. Devices are selected by the attending surgeon but are paid for by the hospital, which has limited ability to influence the choice of device or the rates at which it is reimbursed by Medicare and private insurers for devices.

The purpose of the present study was to measure the variance in total hip and knee replacement implant costs, both within and across hospitals, and to quantify the association between implant costs and hospital characteristics after adjusting for patient diagnoses, comorbidities, and hospital characteristics.

Materials and Methods

Data on Patients, Devices, Hospitals, and Hospital Markets

We obtained data on patients who had been admitted to sixty-one hospitals in 2008 for total knee replacement or total hip replacement. These sixty-one hospitals either participated in the value-based purchasing initiative of the Integrated Healthcare Association, a coalition of large hospitals, medical groups, and health plans in California, or worked on value purchasing with Aspen Healthcare Metrics, a hospital consulting firm. We limited the analysis to patients who underwent unilateral primary total hip or knee replacement surgery. We included patients who were covered by Medicare or commercial insurance but excluded the small number of patients who had no insurance or who were covered by Medicaid. Aspen Healthcare Metrics provided an analytic file with detailed de-identified information on each patient and the hospital in which each procedure was performed.

Device costs were measured in terms of the aggregate price paid by the hospital for the entire joint implant construct. For knee replacement, the construct typically included a femoral component, a tibial component, a tibial insert, and, in some cases, a polyethylene patellar button. For hip replacement, the construct typically included a femoral stem, a femoral head, an acetabular component (including screws and hole covers, when used), and, in some cases, an acetabular liner. The variance in device costs across patients reflected both the prices charged by each vendor to each hospital for each component and type of device and the surgeon's choice of device. These cost data were derived from the hospitals' financial accounting systems, operating room logs, and patient records and indicated the amount actually paid by the hospital to the device manufacturer or distributor. We excluded patients whose recorded device costs were below the 1st percentile or above the 99th percentile in the distribution of device costs across the entire study population in order to reduce the sensitivity of the analysis to data-entry errors or outlier cases. As a check on this data trimming, we also conducted all analyses on the full patient population.

The data file included information on patient age, principal diagnoses, number of comorbidities, discharge destination, and number of in-hospital complications. Coded diagnoses included fracture, osteoarthritis, rheumatoid arthritis, and osteonecrosis. We obtained information on the number of comorbidities, which were defined by Aspen Healthcare Metrics as preexisting conditions that, because of their presence in a patient undergoing the target

surgical procedure, resulted in an increase in the length of stay by at least one day. Surgical complications were defined as including in-hospital events serious enough to result in at least one extra day of hospital stay.

We also collected data on the characteristics of the hospital where the procedure was performed, including the number of total joint replacement procedures performed during the year and the percentage of cases attributable to each device manufacturer within each of the sixty-one hospitals. To measure the extent to which the hospital consolidated its device purchases from a small number of vendors, we calculated the percentage of hip and knee replacement devices purchased from the two vendors with the largest market shares in each hospital. As a comparison, we also analyzed the percentage of devices purchased by each hospital from its single largest vendor and from its four largest vendors.

Additional data on the hospitals where the procedures were performed were obtained from the American Hospital Association's 2008 Annual Survey of Hospitals⁷, including number of staffed beds and the teaching status of the institution. The Herfindahl-Hirschman Index⁸ was used as a measure of market competition, with low values (minimum, 0) indicating a competitive market and high values (maximum, 100) indicating a monopoly. The sixty-one hospitals in the present study were distributed across eight states. To control for the effect of market size, we also measured the population of the metropolitan regions served by each hospital.

Statistical Methods

We calculated the distribution of implant costs across patients, including the minimum and maximum costs as well as the 1st, 25th, 50th (median), 75th, and 99th percentiles. We also calculated the distribution of total procedure costs and the percentage of total procedure costs accounted for by the cost of the implanted device. We calculated the average device cost across the sixty-one hospitals in our sample, plus the percentage of each hospital's device purchases during the year that came from the two device vendors from which the hospital purchased the largest share of its devices.

Device costs vary as a result of patient-specific and non-patient-specific factors that differ within and across hospitals. Patient-specific factors include differences in diagnosis and severity of illness. Across-hospital factors include the hospital's device-purchasing strategy and other hospital characteristics, such as number of beds, annual procedure volume, and teaching status. Within-hospital, non-patient-specific factors include physician-specific preferences that influence device choice as well as differences in the prices charged by different manufacturers to the same hospital. One purpose of the present study was to allocate the total measured variance in device costs across these three sets of factors. It should be emphasized that our measure of cost is the amount actually paid by the hospital to the device manufacturer or distributor. It is not the list price (the hospital typically negotiates an actual price lower than the list price) or the manufacturer's cost (e.g., the resources expended to develop, manufacture, and distribute the device).

We disaggregated the total variation in device costs across patients into three components. The first component was the variation associated with patient characteristics such as age, diagnoses, and comorbidities. The second component was the variation associated with the hospital at which the patient was managed due to the ability of some hospitals to negotiate lower prices with device manufacturers. Both of these components of variation were calculated directly with use of multivariate regression techniques. The third component was the variation associated with different choices of device by the surgeons working in the same hospital, based on their clinical preferences. This third component of total variation was estimated by subtracting the first two components (those associated with patient characteristics and hospital characteristics) from total variation.

We also conducted multivariate statistical analyses of the factors associated with device costs for individual patients. Device costs for each patient were regressed on a set of hospital characteristics, including medical device vendor concentration, annual total knee replacement and total hip replacement procedure volume, staffed beds, and teaching status, plus patient characteristics (age, diagnoses, comorbidities, complications, discharge destination, Medicare versus commercial insurance coverage), hospital market structure, and population size in the local market⁹.

TABLE I Costs Across Patients Undergoing Knee and Hip Replacement Surgery

	Knee Replacement			Hip Replacement		
	Device Cost (U.S. dollars)	Total Surgical Cost (U.S. dollars)	Ratio of Device Cost: Surgical Cost	Device Cost (U.S. dollars)	Total Surgical Cost (U.S. dollars)	Ratio of Device Cost: Surgical Cost
Minimum	1797	7129	12.71%	2392	7152	14.96%
1st percentile	2290	7465	20.17%	2683	7565	23.90%
25th percentile	4183	9891	35.76%	5034	10,732	41.80%
Median	4857	11,660	43.48%	6072	12,548	50.17%
75th percentile	6249	14,013	52.22%	7636	14,595	58.05%
99th percentile	11,143	21,954	70.36%	11,643	21,715	78.72%
Maximum	12,093	23,264	87.07%	12,651	23,051	87.24%

Source of Funding

The present study was funded by the California HealthCare Foundation and Blue Shield of California Foundation. The funds were used for salaries and supplies. The California HealthCare Foundation and Blue Shield of California Foundation had no role in the design and conduct of the study; in the collection, management, analysis, and interpretation of the data; or in the preparation, review, or approval of the manuscript.

Results

The hospitals participating in the present study were major providers of hip and knee replacement procedures in 2008, performing a total of 10,155 total knee replacements and 5013

total hip replacements. Medicare covered 67% of the patients undergoing total knee replacement and 60% of the patients undergoing total hip replacement, with commercial insurance covering the remainder.

Table I presents the distribution of implant costs, total procedure costs, and implant costs as a percentage of total procedure costs per case for total knee and hip replacement. Implant costs varied by a factor of almost seven, from \$1797 to \$12,093 (in 2008 U.S. dollars), for total knee replacement and by a factor of more than five, from \$2392 to \$12,651, for total hip replacement. Total procedure costs varied by a factor of

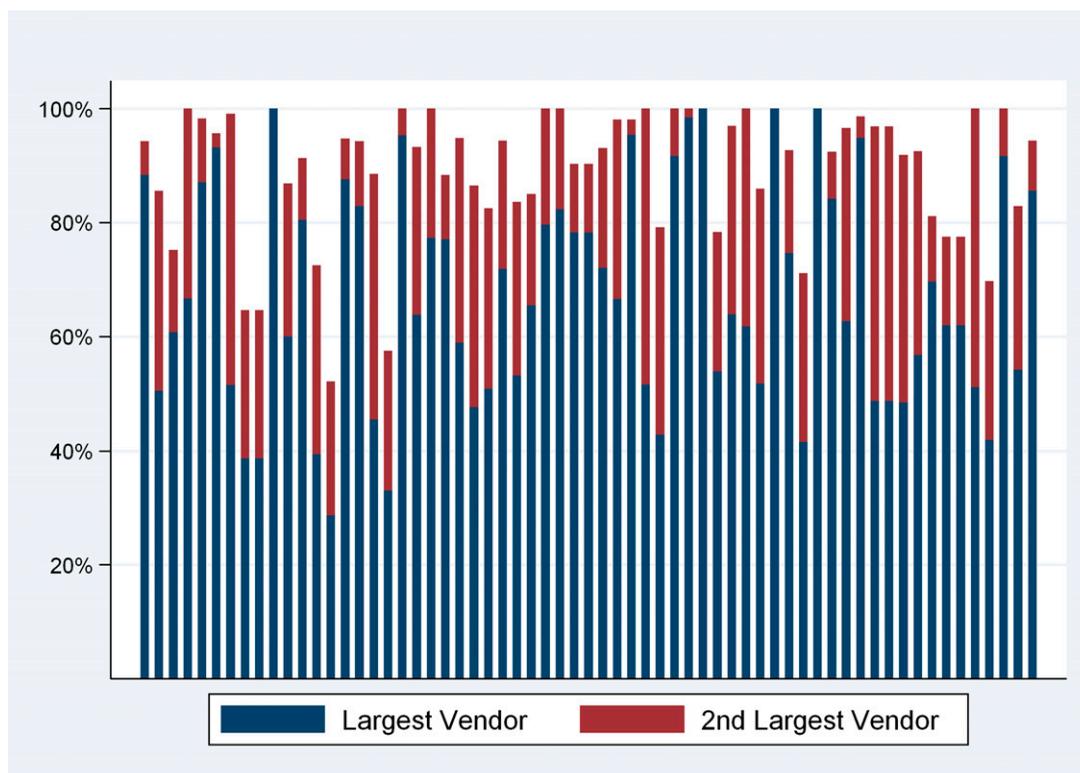


Fig. 1
Histogram showing the percentage of implants purchased from the largest and second-largest device vendors across sixty-one hospitals in 2008.

TABLE II Percentage of Medical Device Costs Attributable to Hospital Characteristics, Patient Condition, Severity, and Physician Preferences

	Knee Replacement (N = 10,155)	Hip Replacement (N = 5013)
Patient characteristics	2.5%	4.4%
Hospital characteristics	61.0%	36.1%
Residual factors, including physician preferences	36.5%	59.5%

more than three for total knee replacement and for total hip replacement. The cost of the device represented a large share of the total cost of each procedure, ranging from 13% to 87% for total knee replacement and from 15% to 87% for total hip replacement.

Table II presents the allocation of total variance in device costs across the three sets of factors. Patient characteristics accounted for only a very small percentage of total variance: 2.5% for knee replacement and 4.4% for hip replacement. After adjusting for patient characteristics, 61.0% of the variance for total knee replacement implants and 36.1% of the variance for total hip replacement implants was associated with hospital characteristics. The residual variance not accounted for by patient and hospital characteristics accounted for 36.5% of total variance for total knee replacement implants and 59.5% of total variance for total hip replacement implants.

As shown in Figure 1, the percentage of total knee replacement and total hip replacement implants obtained from the two vendors with the highest market share within a particular hospital ranged across hospitals from a low of 52% to a high of 100%, with a mean of 90%. By way of comparison, national sales for knee and hip replacement implants are distributed among five major vendors, with the top three accounting for 70% of the market¹⁰.

Table III presents multivariate regression results for the correlates of implant costs across the two study procedures. Age, payer (Medicare), complications, discharge disposition (discharge to acute or post-acute care facility), and a diagnosis of fracture (for total knee replacement only) were all associated with higher device costs after controlling for all other patient, hospital, and market factors. The concentration of device costs in the two vendors with the highest market shares was positively associated with device costs for both procedures, but the association was modest in scale and was not significant. Ten additional points in the percentage of devices purchased from the two largest vendors were associated with device costs that were higher by \$205 ($p = 0.09$). Teaching hospitals had lower adjusted costs for both total hip replacement ($-\$876$) and total knee replacement ($-\$119$), but these differences were not significant. After adjusting for patient and hospital characteristics, procedure volume was not associated with device costs for total knee replacement or total hip replacement.

Our statistical results were not sensitive to the assumptions made concerning the measurement of device costs and procedures. Similar results were obtained when device costs were

TABLE III Multivariate Regression Coefficients for Covariates of Cost of Implantable Device per Patient (U.S. Dollars)*

	Knee Replacement (N = 10,532)	Hip Replacement (N = 5214)
Annual number of procedures	-0.16 (-1.52 to 1.19)	0.54 (-0.39 to 1.46)
Percent of devices from two largest vendors	17.52 (-15.66 to 50.69)	21.02 (-3.63 to 45.66)
Teaching hospital	-876.28 (-2124.80 to 372.24)	-118.70 (-1060.00 to 822.59)
Number of staffed beds	0.21 (-1.55 to 1.98)	0.07 (-1.35 to 1.50)
Market concentration	11.77 (-8.05 to 31.58)	7.63 (-19.78 to 35.05)
Market population (1000s)	-0.04 (-0.12 to 0.04)	-0.04 (-0.11 to 0.03)
Age	-15.16† (-28.43 to -1.88)	-37.28‡ (-49.57 to -24.99)
Medicare patient	164.13† (3.09 to 325.17)	253.18‡ (64.80 to 441.55)
Comorbidities	-90.11 (-365.04 to 184.83)	-84.90 (-260.34 to 90.53)
Complications	377.44† (24.50 to 730.38)	104.21 (-257.72 to 466.14)
Discharge to home	-901.89† (-1543.64 to -260.15)	-489.82† (-898.91 to -80.73)
Osteoarthritis	-619.49 (-1872.71 to 633.73)	252.49 (-171.42 to 676.39)
Rheumatoid arthritis	-144.90 (-459.44 to 169.63)	-178.55 (-598.56 to 241.45)
Osteonecrosis	-44.52 (-493.17 to 404.12)	-29.39 (-278.31 to 219.53)
Fracture	3048.29‡ (1012.16 to -5084.42)	5.04 (-560.79 to 570.87)
R ²	0.07	0.06

*The 95% confidence intervals are given in parentheses, where appropriate. † $P < 0.05$. ‡ $P < 0.01$.

measured in logarithmic rather than natural (dollar) units, when the parameters were estimated with use of the general linearized model with a gamma distribution and log link rather than ordinary least squares, when device cost data were not trimmed at the 1st and 99th percentiles, or when the concentration of purchases was measured in terms of the percentage of purchases from the vendor with the largest total volume or the four vendors with the largest volumes (as a test of the robustness of measuring the concentration of purchases in terms of the percentage obtained from the two vendors with the highest volumes).

Discussion

The costs of joint implant constructs used for total knee replacement or total hip replacement vary widely and are major contributors to the variation in the total cost of care for patients undergoing total joint replacement. Policymakers and health services researchers have pointed out the geographic variations in the rate at which procedures are performed^{11,12}. The results of the present study suggest that commensurate attention should be devoted to variation in the costs of the procedures themselves and of their principal components, including implant costs.

Only 3% to 4% of the variation in device costs for these procedures was related to patient age, diagnosis, and comorbidities. Another 36% to 61% was associated with the hospital in which the procedure was performed. However, the hospital characteristics that we were able to measure and that are frequently referred to in discussions of implant pricing do not explain much of this hospital-associated variation. In particular, the annual volume of knee and hip replacements performed in the hospital, the concentration of implant purchases among a small number of vendors, and hospital bed size were only weakly associated with implant costs. Moreover, we found that much of the variance in device costs was related to variance within, rather than across, hospitals. Even after adjusting for patient characteristics and taking full account of across-hospital variance in costs, 37% to 60% of total variance in implant costs remained unexplained.

This residual variance (the fraction not explained by patient or hospital characteristics) was due to within-hospital factors that we were unable to measure. As the choice of total joint replacement implant is made by the surgeon, we believe that a major determinant of this residual variance in implant costs is within-hospital differences in physician preferences for different implants and alignment between the physicians and the implant manufacturer or the hospital. However, we have no direct information on the training or implant preferences of the individual surgeons practicing in the hospitals involved in the present study. Furthermore, we have no direct information on the economic association of the physicians to the implant manufacturers or the hospitals where they practice.

Our results need to be interpreted within the limitations of the study. The data were derived from hospital cost accounting systems and patient records, which are imper-

fectly standardized across facilities. Differences across hospitals in accounting methods, however, cannot explain the within-hospital variations in device costs. Furthermore, there is no reason to believe that accounting methods are correlated systematically with the number of knee and hip replacement procedures performed per year or with the percentage of devices purchased from the largest two vendors. Therefore, variation in cost accounting methods would not be expected to bias our statistical analyses. We were unable to evaluate the clinical outcomes of the hip and knee replacement procedures studied. While our data did capture in-hospital complications, they were not structured to measure either post-discharge or long-term outcomes such as enhanced patient functional ability, reduced pain, readmission, or device failure. Furthermore, our data only measured the number, not the type, of comorbidities and complications severe enough to cause a one-day extension in length of stay.

An American Joint Replacement Registry is currently being developed to track the outcomes of hip and knee replacement procedures in the United States^{4,13}. When combined with cost data of the sort presented here, utilization and performance data from joint replacement registries will be able to distinguish whether patients who receive higher-cost devices have commensurately better outcomes than patients who receive lower-cost devices.

The principal conclusion that we derived from our analysis was that there is wide variance in device costs that cannot be explained by patient characteristics. Approximately half of this unexplained variance is due to variance across hospitals and approximately half is due to variance within hospitals, e.g., across the different surgeons working in the same facility. The unexplained variance may be due to factors such as idiosyncrasies in physician choice of implant or alignment between the physician and the hospital (e.g., gainsharing) or the physician and the device manufacturer (e.g., consulting arrangements). The large unexplained variance suggests that efforts can be made to reduce implant costs if better data on the comparative effectiveness of implants are developed and better alignment is achieved between physicians and hospitals. ■

James C. Robinson, PhD, MPH
Alexis Pozen, BA
Samuel Tseng, PhD
University of California, Berkeley,
Berkeley Center for Health Technology,
300 Lakeside Drive, Suite 1980, Oakland, CA 94612

Kevin J. Bozic, MD, MBA
UCSF Department of Orthopaedic Surgery and Philip R. Lee
Institute for Health Policy Studies, 500 Parnassus,
MU 320W, San Francisco, CA 94143-0728.
E-mail address: kevin.bozic@ucsf.edu

References

1. Fischer ES, Bell JS, Tomek IM, Esty AR, Godman DC. Trends and regional variation in hip, knee, and shoulder replacement. In: Dartmouth Atlas Surgery Report. Hanover, NH: The Dartmouth Institute for Health Policy and Clinical Practice; 2010 Apr 6.
2. Mendenhall S. 2011 Hip and knee implant review. *Orthopaedic Network News*. 2011;22.
3. Lansky D, Milstein A. Quality measurement in orthopaedics: the purchasers' view. *Clin Orthop Relat Res*. 2009;467:2548-55.
4. Ketcham JD, Furukawa MF. Hospital-physician gainsharing in cardiology. *Health Aff (Millwood)*. 2008;27:803-12.
5. Hackbarth G, Reischauer R, Mutti A. Collective accountability for medical care—toward bundled Medicare payments. *N Engl J Med*. 2008;359:3-5.
6. Weinstein JN, Clay K, Morgan TS. Informed patient choice: patient-centered valuing of surgical risks and benefits. *Health Aff (Millwood)*. 2007;26:726-30.
7. Stewart K, Bardo S, Hu C. Orthopedic Survey: an assessment of the current state of affairs. Credit Suisse Equity Research. 2009.
8. U.S. Department of Justice and Federal Trade Commission. Horizontal merger guidelines. 1997 Apr 8. www.justice.gov/atr/public/guidelines/hmg.htm. Accessed 2010 Mar 21.
9. Greene WH. *Econometric analysis*. 6th ed. Upper Saddle River, NJ: Pearson Education; 2008.
10. Mendenhall S. 2008 U.S. hip and knee implant market. *Orthopedic Network News*. 2009;20:6-8.
11. Weinstein JN, Bronner KK, Morgan TS, Wennberg JE. Trends and geographic variations in major surgery for degenerative diseases of the hip, knee, and spine. *Health Aff (Millwood)*. 2004;Suppl Variation: VAR81-9.
12. Orszag, P. R. Geographic variation in health care spending. www.cbo.gov/doc.cfm?index=8972&type=1. Accessed 2011 Feb 28.
13. American Academy of Orthopaedic Surgeons. American joint replacement registry project. www6.aaos.org/news/pemr/JointRegistry/JointRegistry.cfm. Accessed 2010 Mar 21.