



Variation in the cost of care for primary total knee arthroplasties

Citation

Haas, Derek A., and Robert S. Kaplan. 2016. "Variation in the cost of care for primary total knee arthroplasties." *Arthroplasty Today* 3 (1): 33-37. doi:10.1016/j.artd.2016.08.001. <http://dx.doi.org/10.1016/j.artd.2016.08.001>.

Published Version

[doi:10.1016/j.artd.2016.08.001](http://dx.doi.org/10.1016/j.artd.2016.08.001)

Permanent link

<http://nrs.harvard.edu/urn-3:HUL.InstRepos:32630736>

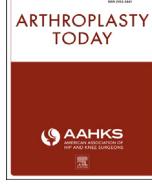
Terms of Use

This article was downloaded from Harvard University's DASH repository, and is made available under the terms and conditions applicable to Other Posted Material, as set forth at <http://nrs.harvard.edu/urn-3:HUL.InstRepos:dash.current.terms-of-use#LAA>

Share Your Story

The Harvard community has made this article openly available.
Please share how this access benefits you. [Submit a story](#).

[Accessibility](#)



Arthroplasty Today

journal homepage: <http://www.arthroplastytoday.org/>

Original research

Variation in the cost of care for primary total knee arthroplasties

Derek A. Haas, MBA ^{a, b, *}, Robert S. Kaplan, PhD ^a

^a Harvard Business School, Boston, MA, USA

^b Avant-garde Health, Boston, MA, USA

ARTICLE INFO

Article history:

Received 3 May 2016

Received in revised form

3 August 2016

Accepted 6 August 2016

Available online 30 September 2016

Keywords:

Costing

Cost variation

TDABC

Total knee arthroplasty

Total joint arthroplasty

ABSTRACT

Background: The study examined the cost variation across 29 high-volume US hospitals and their affiliated orthopaedic surgeons for delivering a primary total knee arthroplasty without major complicating conditions. The hospitals had similar patient demographics, and more than 80% of them had statistically-similar Medicare risk-adjusted readmission and complication rates.

Methods: Hospital and physician personnel costs were calculated using time-driven activity-based costing. Consumable supply costs, such as the prosthetic implant, were calculated using purchase prices, and postacute care costs were measured using either internal costs or external claims as reported by each hospital.

Results: Despite having similar patient demographics and readmission and complication rates, the average cost of care for total knee arthroplasty across the hospitals varied by a factor of about 2 to 1. Even after adjusting for differences in internal labor cost rates, the hospital at the 90th percentile of cost spent about twice as much as the one at the 10th percentile of cost.

Conclusions: The large variation in costs among sites suggests major and multiple opportunities to transfer knowledge about process and productivity improvements that lower costs while simultaneously maintaining or improving outcomes.

© 2016 The Authors. Published by Elsevier Inc. on behalf of The American Association of Hip and Knee Surgeons. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Health care providers are coming under greater financial pressure, especially from more value-based and accountable payment methods. To cope, they need to understand their costs accurately over the full course of treatment by medical condition. Previous efforts to understand cost variation across providers have used measurement approaches that did not reflect the actual cost of the people and equipment used to deliver care. For example, studies of abdominal and congenital heart surgery [1,2] used the ratio of cost-to-charges (RCC) method, a widely-used but inaccurate health care costing method. The RCC method assumes that the cost to perform each service is the same percentage of the charge for each service.

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.2016.08.001>.

* Corresponding author. Soldiers Field, Boston, MA 02163, USA. Tel.: +1 617 496 5726.

E-mail address: dhaas@hbs.edu

For instance, if total costs in a unit are \$1.2 million and total charges are \$2 million, the RCC method estimates the cost to perform each service as 60% of the service's charge. While the RCC approach is simple to understand and easy to implement, it is inaccurate because the charges have not been established based on actual costs of resources used to deliver each service.

We applied time-driven activity-based costing (TDABC) to study the cost variation for performing total joint arthroplasties (TJAs) at 29 high-volume hospitals. TDABC, a bottoms-up approach, uses process mapping to identify the types and costs of all personnel utilized in each step of a complete cycle of care [3–6]. TDABC has previously been used to examine the costs of TJAs at individual sites [7,8].

TJAs are one of the most commonly performed major surgeries in the country. Currently, more than 1 M joint arthroplasties are performed per year in the United States, and the number is projected to reach 4.05 M per year by 2030 [9,10]. Also, motivating this study is the increased use of bundled payments for joint arthroplasties, which causes hospitals to become more financially accountable for their costs of care. The Centers for Medicare and Medicaid Services introduced bundled payments in 2013 through a Bundled Payments for Care Improvement initiative, comprised of 4 models of bundled payments across a range of medical and surgical

conditions, including TJAs. In April 2016, Centers for Medicare and Medicaid Services introduced the Comprehensive Care for Joint Replacements model for primary TJAs. This payment initiative holds hospitals financially accountable for all related Medicare Part A and B expenditures from the time of hospital admission through 90 days post discharge [11]. Beyond these public payer programs, a national alliance of leading providers has been established to offer orthopaedic surgeries at a fixed bundled price directly to large employers and employer groups [12].

The present study brought together 29 US-based sites to facilitate the measurement of their direct costs of providing a total knee arthroplasty (TKA) and help them to understand the primary drivers of cost variation across providers. Overall, Medicare data indicate that 95%–97% of hospitals were not statistically different from one another on risk-adjusted complication and readmission rates for TKAs (Table 1) [13]. While these quality measures are not comprehensive, the little variation among them indicates large opportunities to reduce the variation in costs of TKAs without adversely impacting outcomes. Previous research has documented wide variation in reimbursement rates and hospital and physician charges [14,15]. A recent study showed a 380% variation in reimbursement rates across the country for TKAs, including as much as a 2.67 \times difference within a single geographic market [16]. These studies, however, have not compared providers' actual costs for delivering TKAs over an entire cycle of care.

Material and methods

The article authors and the Institute of Healthcare Improvement organized a Joint Replacement Learning Community during calendar year 2014 to measure the value and improve the performance of the participating hospitals ("sites"). Hospitals that performed at least 200 primary TJAs in the prior year were eligible to participate. Thirty-two hospitals enrolled in the program, 29 were from the United States. The participating hospitals performed an average of 800 TJAs in 2013.

Nine of the US-based hospitals were academic medical centers; 20 were community hospitals. Their TJA patients had similar average age (65 years) and body mass index of 31 [17]. We excluded cases with major complicating conditions by studying only cases equivalent to a Medicare Severity-Diagnosis Related Group (MS-DRG) of 470. Twenty-four of the providers had risk-adjusted readmission and complications rates for TJAs that were no different than average based on Medicare Hospital Compare data. Two organizations had rates that were statistically better than average, and 3 organizations were worse on one or both outcome dimensions [13].

The analysis included costs over a care cycle that started with the initial office visit at which the decision for surgery was made and concluded 90 days post discharge. It included the costs of care delivered by physicians, whether employed at the hospital or not, and for postacute care, such as for rehabilitation and therapy.

Table 1
Medicare risk-adjusted complication and readmission rates [10].

Comparison	Risk-adjusted complication rate (%)	Risk-adjusted readmission rate (%)
Better than US national rate	3	2
No different than US national rate	95	97
Worse than US national rate	2	1

Source/notes: Hospital Compare data. 2015 [cited 2015 April 12]. Available from: <https://data.medicare.gov/>

Except for the postacute care costs, the analysis focused on direct personnel and consumable supply costs. We excluded space and equipment costs since our previous research projects found these costs to be less than 10% of personnel and supply costs [18]. We also excluded indirect costs, such as information technology, human resources, and billing, as assigning these costs accurately would have required extensive cost modeling and analysis for every indirect and overhead cost category in the hospital.

We used TDABC to measure the direct personnel costs and trained the sites on the approach [4–6]. TDABC involves identifying the clinical and administrative activities performed over the care cycle, including the types of clinicians and staff members that perform each activity and the amount of time each personnel type spends on each activity. The second step in the TDABC process calculates the cost per minute for each of the personnel types used in the care cycle. The cost per minute divides the fully loaded cost for each type of personnel (compensation plus benefits) by the quantity of time that each personnel type has available for performing productive work per year on average. The employee activity time is then multiplied by the employee's cost per minute and summed across all employees to calculate total personnel costs. For example, if a nurse spends 20 minutes with a patient during an office visit (inclusive of prep and follow-up time), and the fully loaded cost for that nurse is \$1.50/minute, then the cost of nursing time for the visit is \$30. The cost of all of the resources utilized as part of a particular service (eg, a clinic visit, a rehabilitation session, or a surgical intervention) can then be summed together to determine the total cost of that service [3].

The organizations used actual purchase prices, the price the organization paid to the manufacturer or distributor, as the cost for consumable supplies. For postacute care costs, the organizations used internal cost estimates when they provided the service and external claims data when internal cost data were not available.

The unit of analysis for the study was the average cost to deliver the care for primary TKAs at each site. The project teams reported their cost data in a common format with a web-based system, developed by the study authors, which then calculated the TDABC costs for each site. The authors analyzed the consolidated data to compare costs across sites for the complete care cycle, as well as for important segments within the care cycle, such as preoperative, day of surgery, postacute care, and for different categories of expense, principally personnel and purchased supplies. A unique capability of the TDABC costing approach enabled the authors to use accounting variance analysis to adjust for differences in labor cost rates across the sites [19]. The authors could also identify the variation in postacute care spending caused by differences in payments for different types of postacute care services (eg, home health care vs skilled nursing facility) across sites.

The sites had the option to either report costs for the site on average or to provide a breakdown of costs based on the practices of individual physicians. In the latter situation, we used an average cost across physicians for those sites.

The authors performed a separate analysis of the costs of the prosthetic implant, the largest single cost component for TKAs [20]. The sites replied to a survey asking them to report the average purchase price for prosthetic implants used in primary TKA procedures for DRG 470 over the 12 months ending September 30, 2013. They reported their average purchase price with in \$500 ranges. For statistical analysis, we used the midpoint of each price point range [21].

Results

Table 2 summarizes the variation in costs across the 29 sites. Due to nondisclosure agreements with the participating hospitals, we show the cost comparisons in indexed form, rather than the actual

Table 2

Distribution in indexed costs for primary total knee arthroplasties.

Measure	Higher percentile is a higher cost. Unit of analysis is a hospital and affiliated surgeons.					
	10th percentile	25th percentile	Median	75th percentile	90th percentile	Ratio of 90th to 10th percentile
Total personnel and consumable supply costs for hospital stay and orthopaedic office visits	0.77	0.88	1.00	1.09	1.24	1.6
Total consumable supply costs	0.62	0.90	1.00	1.08	1.41	2.3
Prosthetic implant cost	0.58	0.79	1.00	1.11	1.23	2.1
Bone cement costs	0.22	0.52	1.00	1.68	3.81	17.4
Total personnel costs	0.59	0.77	1.00	1.13	1.37	2.3
Total standardized personnel costs	0.68	0.82	1.00	1.14	1.31	1.9
Standardized personnel costs before day of surgery	0.57	0.84	1.00	1.62	2.10	3.7
Standardized personnel costs day of surgery before surgery	0.59	0.69	1.00	1.48	1.85	3.1
Standardized personnel costs during surgery	0.61	0.78	1.00	1.33	1.64	2.7
Standardized personnel costs in the postanesthesia care unit (PACU)	0.59	0.85	1.00	1.38	1.63	2.8
Standardized personnel costs during inpatient stay	0.74	0.84	1.00	1.14	1.35	1.8
Standardized personnel costs during postdischarge follow-up visits	0.34	0.53	1.00	1.43	2.00	5.9
Readmission cost	0.53	0.73	1.00	1.36	1.58	3.0
Standardized postacute care costs	0.74	0.88	1.00	1.22	1.63	2.2

Source/notes: Data from 29 JRLC partner sites.

cost data. We report the median cost in each cost comparison as 1.00; values greater than 1 represent higher costs and values below 1 represent lower costs. Higher percentiles represent higher costs (eg, for a site at the 90th percentile, 90% of sites had costs lower than it). The total personnel and consumable supply costs for the site at the 90th total cost percentile were $1.6 \times$ (60%) greater than the costs of the site at the 10th percentile. A site at the 90th percentile for total personnel and supply costs that improved to the 75th percentile would save 12%; a site at the 75th percentile that improved to the median would save 8%; a site at the median that improved to the 25th percentile would save 12%; and a site at the 25th percentile that improved to the 10th percentile would save 13%.

On average, consumables represented 59% and personnel 41% of personnel and supply costs. There was a $2.3 \times$ range in consumable costs between the 90th and 10th percentiles. Prosthetic implants, the largest consumables expense, had a $2.1 \times$ range between the 90th and 10th percentiles [20]. Other types of consumables had a much larger range. The cost of bone cement, for example, was $17 \times$ higher for the 90th percentile site than for the site at the 10th percentile. While we are not able to quantitatively explain all the variation in bone cement costs, anecdotally, the variation was caused by having different purchase prices for the same type of cement, using different types of cement (eg, premixed antibiotic cement is more expensive than hand-mixed or plain bone cement) and using different quantities of cement during the actual procedure.

Total personnel costs had a $2.3 \times$ range between the 90th and 10th percentiles, for example, the site at the 90th percentile spent 130% more on personnel than the site at the 10th percentile. Some of the cost variation across the hospitals could be attributed to the different compensation paid by each site to similar types of comparable employees (called a price variance by accountants). We controlled for this source of variation by also calculating costs using an average wage and benefit rate for each personnel type at all sites, for example, if we were doing a comparison across only 2 sites (instead of the 29 actually used) and site 1's nurses cost \$1/minute while site 2's cost \$1.5/minute, we would use an average rate of \$1.25/minute for the cost of nursing time at each site when calculating standardized personnel costs. Total personnel costs after standardization still had a $1.9 \times$ difference between the 90th and 10th percentiles. This variation, called a quantity or productivity variance, is exclusively due to differences in the mix of personnel

utilized and the quantity of time each type spent over the episode of care, factors that are much easier to change than local, and site-specific compensation rates.

We analyzed personnel cost variation at each stage of the care cycle: before day of surgery, day of surgery before the operation, surgical operation, postanesthesia care unit stay, inpatient stay, and postoperative orthopaedic follow-up visits. The greatest variation in personnel costs occurred during the postoperative follow-up visits, with a $5.9 \times$ range in costs from the 90th to the 10th percentiles. Since most sites had 2 follow-up visits within 90 days of discharge from the operation, the variation in follow-up visit personnel costs was driven by which employees saw patients and the time each spent with them during each follow-up visit, rather than by the number of visits.

The inpatient floor hospitalization costs were driven primarily by nursing costs. After standardizing for differences in wage rates among sites, the 2 largest drivers of nursing expenses were the length of the patient's hospital stay and the patient-to-nurse staffing ratio (ie, how many patients each nurse was expected to care for).

Cost estimates for patients discharged to the various types of postacute care (inpatient rehabilitation, skilled nursing facility, home with home health care, and home with outpatient therapy) varied by at least $6 \times$ between the 90th and 10th percentiles. We again used variance analysis by calculating an average cost for each type of postacute care. This enabled us to focus our analysis on the mix of postacute services used across hospitals. A $2.2 \times$ variation between the 90th and 10th percentiles for postacute care costs still remained. The variation was due to variation in discharge disposition (the type of setting patients were discharged to) and readmission rates, with most of the variation due to discharge disposition. We found no correlation between performing statistically better or worse than average on the Medicare Hospital Compare metrics and standardized personnel costs. We also found no correlation between standardized personnel costs up through discharge and standardized postacute care costs.

Discussion

Personnel costs were highest for the surgical operation and the inpatient hospitalization stay. The primary drivers of surgical operation costs were the duration of the operation, including time

Table 3

Quartiles of postacute care spend and discharge disposition.

Quartiles of postacute care spend	Home with outpatient (%)	Home health (%)	Inpatient rehabilitation (%)	Skilled nursing facility (%)	Readmissions (%)
Highest	4	42	24	29	3
2nd highest	17	50	4	29	3
2nd lowest	23	57	7	13	3
Lowest	44	42	4	10	2

Source/notes: Data from 29 JRLC partner sites.

spent prepping and cleaning the room, and the mix of staff members used at each stage of the operation. Surgeons are by far the most expensive personnel type. Surgeons at the sites with the lowest surgical personnel costs per patient (after standardizing for differences in labor cost rates across sites, which varied by over 60%) had shorter surgery times either because they were faster or, more commonly, were present for fewer process steps of the surgery. At the low surgical personnel cost sites, the surgeon's time lasted only from first incision to the time closure began, at which point the surgeon left to prepare for the next case in a second operating room. Lower cost (but still qualified) staff members performed the remaining functions, including closure. From a productivity perspective, most of the surgeons who performed at least 300 TJAs per year had access to two operating rooms, half the surgeons who performed between 100 and 300 cases per year used 2 operating rooms, while all of the surgeons who performed under 100 cases per year had access to only 1 operating room for their procedures.

The cost of a surgeon with access to only 1 operating room is much higher, as the surgeon's time includes the actual operating time plus the time spent waiting for the current case to be finished, for the room to be cleaned and prepared, and for the next patient to be transferred to the room. A conflict can therefore arise between hospitals that want high utilization of their expensive operating rooms and surgeons who want high utilization of their time. Accurate cost accounting helps to resolve this conflict. Representative numbers based on our prior (unpublished) work have shown that, on average, a fully equipped operating room costs about \$0.50 per minute of the available time. A fully staffed surgical team, including the surgeon, costs \$10-\$20 per minute. Even excluding the surgeon from the analysis, the cost per minute for the rest of the operating room team is typically above \$5 per minute, an order of magnitude higher than the space cost. A hospital striving to get maximum utilization of its most expensive resources should learn how to keep its skilled surgical teams as productive as possible.

The other principal source of variation in day of surgery costs was the 2.1 to 1 variation (90th to 10th percentiles) due to implant purchase prices. A statistical analysis revealed that the most statistically and economically significant variable to explain this large variation was whether a joint committee of hospital administrators and surgeons made the purchase decision and negotiated with vendors [20]. Sites that used such a joint committee paid, on average, 17% less for implants than those without a joint purchasing committee. Volume played a statistically significant but small-in-magnitude role (3% reduction per 100 incremental surgeries).

The cost of bone cement also varied widely across sites, largely caused by variation in the type of cement used. For example, pre-mixed antibiotic cement is much more expensive than other types. Research has shown, however, that hospitals do not necessarily need to purchase more expensive bone cement. A recent recommendation made by the American Academy of Orthopaedic Surgeons noted that in most cases, antibiotic cement is unnecessary, providing an actionable way for organizations to reduce costs quickly without compromising patient outcomes [22].

Postacute care was also costly. **Table 3** shows that the major explanation of the variation in costs of postacute care arises from the discharge disposition for the patient. Sites in the lowest quartile of standardized postacute costs discharged less than 50% of their patients to their homes. Sites in the highest quartile discharged less than 50% of their patients to home. Home rehabilitation costs were 20% of the costs of skilled nursing facilities and 15% of the costs for extended inpatient facilities. There was no systematic relationship across sites between the average patient age and the standardized postacute care costs at each site. Several of the low postacute cost care sites reported that they set an expectation for discharge to home rehabilitation in presurgical visits with patients and their families and subsequently reinforced this communication during the hospital stay. During the hospital stay, the sites also designed their pain management and physical therapy to increase a patient's comfort level with being discharged to home. For example, one site used a prototype vehicle for the patient to practice entering and leaving and a 12-step staircase with rails on either side to practice going up and down stairs. While the extra time spent talking with patients and their families and the specialized therapy approaches did involve higher costs, these extra costs were less than \$100 per patient, a savings of thousands of dollars when compared to discharging patients to skilled nursing and specialized rehab facilities. Sites that started physical therapy earlier in the postsurgical stage also discharged a higher percentage of patients to home health care.

Our data and methods are subject to a number of limitations. First is the nonrandomized sample of hospitals in the analysis. The 29 hospitals in the study each performed at least 200 primary TJAs per year, and all chose to participate in the Joint Replacement Learning Community program in 2014. A second limitation is that each hospital self-reported the data. While we continually questioned and challenged the hospitals to confirm that the reported data were correct, we were not able to independently verify the data ourselves. It is thus possible that some of the variation in cost is due to differences in how well and how accurately the hospitals captured information used to calculate the TDABC costs at their institution. A third limitation is that while hospitals had data on the discharge disposition of the patient, they did not have comprehensive data on the postacute care costs for the patients. The variation in postacute care costs is therefore based on the average cost for the discharge disposition used for patients, not the actual full cost for the 90 days post discharge. A fourth limitation, as noted in the **Material and methods** section, is that we did not include space and equipment costs in the analysis based on our prior experience that these do not typically represent a substantial cost on a per patient basis. It is possible though that varying use of advanced technology, such as computer navigation, advanced imaging, robotics, and custom jigs contributes to variation in cost across hospitals.

Conclusions

Hospitals with similar patient demographics and similar patient volumes for TKAs have wide variation in their costs over the TKA care cycle. This large variation suggests a great opportunity to lower

costs while maintaining quality and patient outcomes by identifying and transferring the best practices of sites in the lowest percentiles of cost. These best practices improve the efficiency of care and productivity of employees and facilities, enabling them to handle much of the expected growth in TKA volume without adding costly new capacity. Several sites in the program made immediate and significant improvements based on what they learned from the analysis, such as optimizing the discharge disposition of the patients from the hospital and changing pain management to enable physical therapy to start earlier. Looking forward, policies such as bundled payments will lead to greater price (payment rate) pressure on hospitals, increasing the benefits from proactive management of actual costs over complete episodes of care. TDABC provides both accurate estimates of care cycle costs, as well as greater transparency into the drivers of those costs.

With almost all hospitals publically reporting similar outcomes on complication and readmission rates despite large variation in costs, such efficiency and productivity improvements should be possible while maintaining or improving outcomes. Further efforts, however, should strive to encourage hospitals and clinicians to adopt and report condition-specific patient-reported outcome metrics, which would allow a better comparison and improvement of quality and costs across providers.

Acknowledgments

The authors acknowledge Dr. Anthony DiGioia of Magee-Womens Hospital of UPMC, Dr. Kevin Bozic of Dell Medical School, as well as Katherine Luther, Jill Duncan, Kayla DeVincenzi, and Kevin Little from the Institute for Healthcare Improvement (IHI) for their significant contributions during the Joint Replacement Learning Community, which was the source for the data analyzed in the article. The authors would also like to acknowledge Lila Kelso for her valuable support in preparing the article for publication. The authors received compensation from IHI for their work during the JRLC.

References

- [1] Pasquali SK, Jacobs ML, He X, et al. Variation in congenital heart surgery costs across hospitals. *Pediatrics* 2014;133(3):e553.
- [2] Stey AM, Brook RH, Needleman J, et al. Hospital costs by cost center of inpatient hospitalization for Medicare patients undergoing major abdominal surgery. *J Am Coll Surg* 2015;220(2):207.
- [3] Kaplan RS, Witkowski M, Abbott M, et al. Using time-driven activity-based costing to identify value improvement opportunities in healthcare. *J Healthc Manag* 2015;59(6):399.
- [4] Kaplan RS. Improving value with TDABC. *Healthc Financ Manage* 2014;68(6):76.
- [5] Kaplan RS, Anderson SR. Time-driven activity based costing: a simpler and more powerful path to higher profits. Boston: Harvard Business School Publishing; 2007.
- [6] Kaplan RS, Porter ME. The big idea: how to solve the cost crisis in health care. *Harv Bus Rev* 2011;89(9):46, 54, 56–61 passim.
- [7] Akhavan S, Ward L, Bozic KJ. Time-driven activity-based costing more accurately reflects costs in arthroplasty surgery. *Clin Orthop Relat Res* 2016;474(1):8.
- [8] DiGioia A, Greenhouse P, Giarrusso M, Kress J. Determining the true cost to deliver total hip and knee arthroplasty over the full cycle of care: preparing for bundling and reference-based pricing. *J Arthroplasty* 2016;31(1):1.
- [9] National Hospital Discharge Survey: 2010 table, Procedures by selected patient characteristics—Number by procedure category and age, http://www.cdc.gov/nchs/data/nhds/4procedures/2010pro4_numberprocedureage.pdf [accessed 12.04.16].
- [10] Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *J Bone Joint Surg Am* 2007;89(4):780.
- [11] Press M, Rajkumar R, Conway P. Medicare's new bundled payments: design, strategy, and evolution. *JAMA* 2016;315(2):131.
- [12] National Orthopaedic & Spine Alliance, <http://www.nationalorthospine.com/about-us/> [accessed 04.02.16].
- [13] Hospital Compare Data. 2015, <https://data.medicare.gov/> [accessed 12.04.15].
- [14] Rosenthal JA, Lu X, Cram P. Availability of consumer prices from US hospitals for a common surgical procedure. *JAMA Intern Med* 2013;173(6):427.
- [15] White C, Reschovsky JD, Bond AM. Inpatient hospital prices drive spending variation for episodes of care for privately insured patients. National Institute for Health Care Reform; 2014. p. 8; Research Brief No.:14. <http://www.nihcr.org/Episode-Spending-Variation> [accessed 12.04.15].
- [16] Blue Cross Blue Shield. Blue Health Intelligence. A study of cost variations for knee and hip replacement surgeries in the US. The Health of America Report. 2015. p. 9; Report No.:15-041-R02. <http://bcbs.com/healthofamerica/?referrer=https://www.google.com/> [accessed 12.04.15].
- [17] Hospitals either reported the average age and BMI data for the hospital on average or separately for each of the orthopaedic surgeons that were participating in the study at that hospital. In the latter case we average the values across the surgeons at each hospital to come up with a hospital average. The standard deviation of the average age across hospitals was 2.3 years and the standard deviation of the average BMI was 2.3.
- [18] Kaplan RS, Haas DA. How not to cut health care costs. *Harv Bus Rev* 2014;92(11):116.
- [19] Erhan F, Mistry B, Platckel T, et al. Time-driven activity-based costing of multi-vessel coronary artery bypass grafting across national boundaries to identify improvement opportunities: study protocol. *BMJ Open* 2015;5:e008765.
- [20] Haas D, Bozic K, DiGioia A, Song Z, Kaplan R. Drivers of the variation in prosthetic implant purchase prices for total knee and total hip arthroplasties. *J Arthroplasty*. In press.
- [21] If a site reported that its implant cost was in the \$5,500-\$5,999 range, we used an estimated average purchase price of \$5,750.
- [22] McGrory BJ, Weber KL, Brown GA, et al. Surgical management of osteoarthritis of the knee: evidence-based clinical practice guideline. Rosemont, IL: American Academy of Orthopaedic Surgeons; 2015. p. 8.