Variation in the Cost of Care for Different Types of Joint Arthroplasty

Michael P. Carducci, BA, Gregory Gasbarro, MD, Mariano E. Menendez, MD, Kuhan A. Mahendraraj, BA, David A. Mattingly, MD, Carl Talmo, MD, and Andrew Jawa, MD

Investigation performed at New England Baptist Hospital, Boston, Massachusetts

Background: Lower-extremity arthroplasty constitutes the largest burden on health-care spending of any Medicare diagnosis group. Demand for upper extremity arthroplasty also continues to rise. It is necessary to better understand costs as health care shifts toward a bundled-payment accounting approach. We aimed (1) to identify whether variation exists in total cost for different types of joint arthroplasty, and, if so, (2) to determine which cost parameters drive this variation.

Methods: The cost of the episode of inpatient care for 22,215 total joint arthroplasties was calculated by implementing time-driven activity-based costing (TDABC) at a single orthopaedic specialty hospital from 2015 to 2018. Implant price, supply costs, personnel costs, and length of stay for total knee, total hip, anatomic total shoulder, reverse total shoulder, total elbow, and total ankle arthroplasty were analyzed. Individual cost parameters were compared with total cost and volume.

Results: Higher implant cost appeared to correlate with higher total costs and represented 53.8% of the total cost for an inpatient care cycle. Total knee arthroplasty was the least-expensive and highest-volume procedure, whereas total elbow arthroplasty had the lowest volume and highest cost (1.65 times more than that of total knee arthroplasty). Length of stay was correlated with increased personnel cost but did not have a significant effect on total cost.

Conclusions: Total inpatient cost at our orthopaedic specialty hospital varied by up to a factor of 1.65 between different fields of arthroplasty. The highest-volume procedures—total knee and hip arthroplasty—were the least expensive, driven predominantly by lower implant purchase prices.

Clinical Relevance: We are not aware of any previous studies that have accurately compared cost structures across upper and lower-extremity arthroplasty with a uniform methodology. The present study, because of its uniform accounting process, provides reliable data that will allow clinicians to better understand cost relationships between different procedures.

Health-care spending in the United States increased to $3.5 trillion (or $10,739 per person) in 2017, representing 17.9% of the gross domestic product[1]. Surging expenditure has increased the demand for high-value care, which necessitates restraining costs while maintaining quality. According to Centers for Medicare & Medicaid Services (CMS) Medicare data, hospital care, including elective orthopaedic procedures, constitutes the largest component of Medicare spending. Major joint replacement of the lower extremity, which includes total knee arthroplasty (TKA) and total hip arthroplasty (THA), constitutes 6.3% of all Medicare expenditures, more than any other diagnosis family[2]. Demand for both upper and lower-extremity arthroplasty has increased over the last 20 years[3-6]. Upper-extremity procedures in particular have seen rapid growth in demand, driven largely by improved surgical protocols and the aging population in the United States[5,6].

Previous studies have analyzed cost variance among upper and lower extremity arthroplasty separately. Literature on both shoulder arthroplasty as well as hip and knee arthroplasty has demonstrated that implant price is the main driver of overall inpatient costs to the hospital[7-11]. However, there is a paucity of data directly comparing upper and lower-extremity costs or analyzing determinants of cost across different procedures using

Disclosure: The authors indicated that no external funding was received for any aspect of this work. On the **Disclosure of Potential Conflicts of Interest** forms, *which are provided with the online version of the article*, one or more of the authors checked "yes" to indicate that the author had a relevant financial relationship in the biomedical arena outside the submitted work (http://links.lww.com/JBJS/F601).

an identical methodology. As a result, it is difficult to determine arthroplasty-wide trends that may have an important impact on health-care spending overall.

The aims of the present study were (1) to identify whether variation exists in total cost among different types of joint arthroplasty, and, if so, (2) to determine which cost parameters drive this variation.

Materials and Methods

Study Design

After internal review board approval, we retrospectively identified cost data for patients who underwent elective THA, TKA, anatomic total shoulder arthroplasty (TSA), reverse total shoulder arthroplasty (RSA), total elbow arthroplasty (TEA), and total ankle arthroplasty (TAA) procedures at a single orthopaedic specialty hospital from January 2015 to October 2018. Time-driven activity-based costing (TDABC) methodology was used to determine the cost of an inpatient care cycle after surgery[12,13].

Time-Driven Activity-Based Costing

TDABC is a highly accurate accounting method developed at Harvard Business School with a focus on bundled payments to improve value in health care[11,13]. Two parameters are required: (1) the quantity of time allocated to each patient during an episode of care and (2) the cost per unit or minute of each resource employed during an episode of care[14,15]. The present study focused on inpatient costs across different types of total joint arthroplasty, from check-in on the day of surgery to room cleaning on the day of discharge. Process maps were developed for the preoperative, intraoperative, and postoperative phases. Thus, anesthesia costs and operative costs were separated into supply and personnel categories and then were grouped with other costs in each category. Individual direct costs (supply and personnel) and length of stay were analyzed and compared with total cost and case volume. Personnel costs were calculated by multiplying the cost per minute of each staff member by the amount of time that each staff member spent with each patient. Each position (nurse, resident/fellow, orthopaedic surgeon, etc.) was assigned a salary that was calculated by averaging the salaries of all employees within each position. The cost of each staff member was determined according to the position-based average salary and the number of patients under each staff member's care. We included the services of the attending orthopaedic surgeon, residents, fellows, physician assistants (PAs), nursing staff (through the entire inpatient episode), operating room and radiology staff, anesthesiologist, anesthesiology-certified registered nurse anesthetists (CRNAs), and hospital administrative and patient-care staff by reviewing operative records and time stamps. Only 1 PA and 1 fellow or resident was present on a surgical team at any point in time. All surgical teams were universal, and no surgeons had their own specific team. Busy surgeons were permitted to run >1 operating room in a staggered fashion. Supply costs, including implants, medications, and other supplies (for example, consumables), were determined on the basis of actual purchase prices. Implant costs and discounts were negotiated directly with vendors, and no restrictions of implant choice were placed on physicians. Generally, surgeons were given 1 to 2 trays of individualized instruments; additional instruments occasionally were used as well. Indirect costs (human resources, billing, etc.) were excluded.

Costing, along with length of stay, was calculated with use of software developed by Avant-garde Health[11] with guidance from the hospital director of orthopaedic surgery and financial analysts. Patient-level data were screened by this software for integrity and then were excluded if the check process failed. Across all knee, hip, ankle, shoulder, and elbow procedures, 3.4% of patients were removed because of screening failure during the study period. The costs of consumables were considered to be the actual purchase price of each unit. Demographic, time stamp, care delivered, and utilized drug and supply data were then run through the

TABLE I Ratios of the Mean of Each Cost Category to a Reference Procedure*

Parameter	TKA (N = 10,979)	THA (N = 10,067)	RSA (N = 688)	TSA (N = 392)	TAA (N = 75)	TEA (N = 14)	Average
Implant	1	1.39	2.20	1.88	2.41	2.02	1.98
Medication	1	1.04	1.61	1.42	0.80	1.34	1.24
All other supply cost	1	0.79	1.44	1.58	1.24	2.58	1.53
Personnel cost	1	0.86	0.93	0.89	0.82	1.28	0.95
Preop. through operating room	1	1.06	1.16	1.20	1.07	1.92	1.28
PACU through discharge	1	0.67	0.71	0.61	0.60	0.71	0.66
Total inpatient cost	1	1.07	1.48	1.33	1.48	1.65	1.40
Volume of procedures	1	0.92	0.063	0.036	0.007	0.001	0.20
Length of stay† *(days)*	1	0.71	0.71	0.61	0.60	0.75	0.68

*Reference = TKA. †The average length of stay was 3.14 days for TKA, 2.29 days for THA, 2.27 days for RSA, 1.92 days for TSA, 1.87 days for TAA, and 2.35 days for TEA.

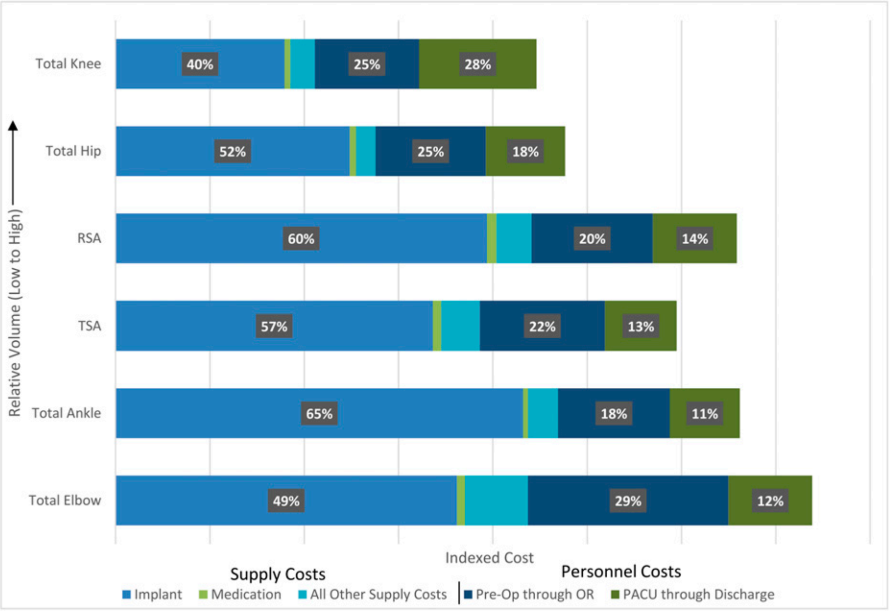

Fig. 1

Bar graph displaying cost parameters as a percentage of total inpatient cost for each type of arthroplasty. Bars are arranged vertically from highest volume (top) to lowest volume (bottom). OR = operating room.

various process maps for each procedure. These process maps were developed on the basis of previous work done by Avantgarde and with interviews and direct observations of clinical staff involved. On the basis of this review, processes were labeled as variable or consistent, generalizable processes. For consistent, generalizable processes (for example, transfer from operating room to post-anesthesia care unit [PACU]), average process times were used, whereas for variable processes (for example, length of stay), manually entered time stamps were used[11].

Statistical Analysis

Proportions and percentages rather than dollar amounts were used to ensure confidentiality of internal hospital cost data. Percentage of total cost was calculated for each cost category

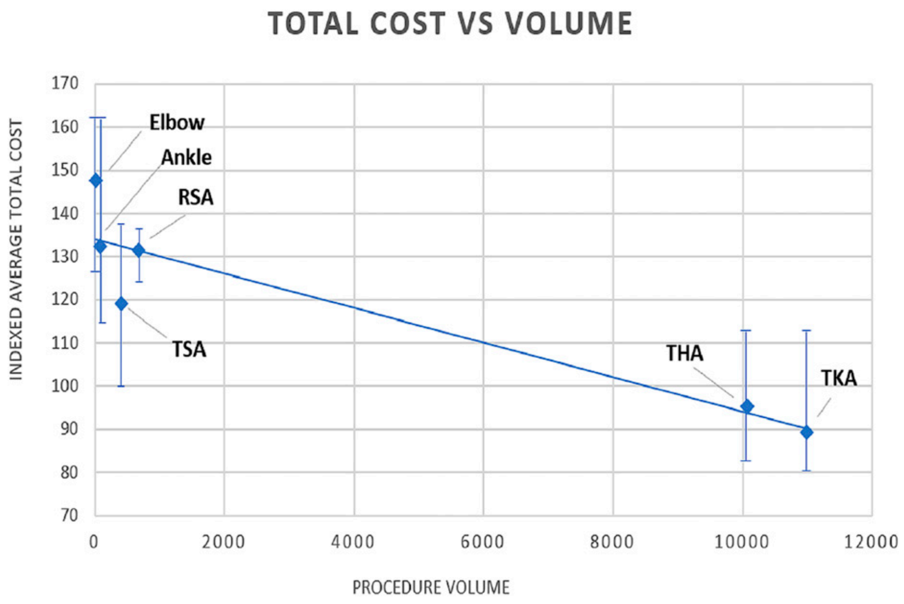

Fig. 2

Scatterplot showing the indexed inpatient cost versus procedure volume for each type of arthroplasty. The error bars indicate the range of indexed total cost of each type of arthroplasty. The highest and lowest indexed cost of each surgery are represented by the end points of each bar.

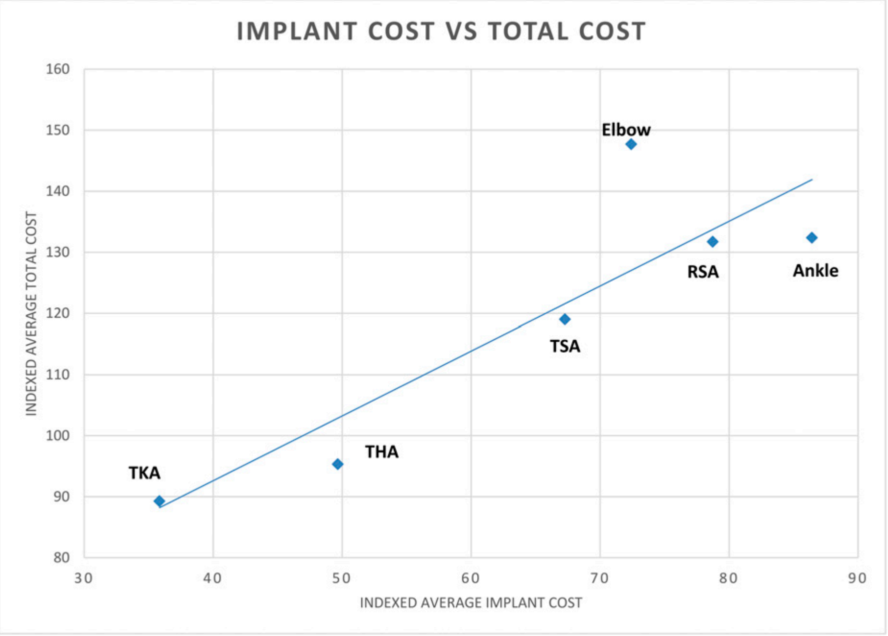

Fig. 3

Scatterplot showing indexed inpatient cost versus scaled implant cost for each type of arthroplasty.

across all types of arthroplasties. These percentages were then used to compare trends in the composition of cost compared with volume. Variability between procedures was determined by a ratio of the mean of each cost category to a reference value. TKA, the least expensive and most common procedure, was used as the reference for all other procedures.

Results

We analyzed 22,215 total joint arthroplasties (Table I) performed by 53 orthopaedic surgeons, all but 1 of whom were fellowship-trained. Twenty-one surgeons performed ≥100 TKAs or THAs, and 2 performed ≥100 TSAs or RSAs. Inpatient TKA and THA were the most numerous and least expensive procedures (Figs. 1 and 2). Conversely, TEA and TAA were the least numerous and most expensive procedures (Figs. 1 and 2). Implant price was the most expensive component of total cost across all types of joint arthroplasty, accounting for an average of 53.8% of arthroplasty costs (Fig. 1). As implant cost increased, so too did total cost across all procedure types (Fig. 3). The proportion of total cost contributed by implant price generally increased as total cost increased and volume decreased (Fig. 1). Meanwhile, personnel cost constituted a similar proportion of costs regardless of total cost. Similarly, length of stay correlated with increased personnel cost but did not appear to be related to total cost or surgical volume (Table I).

Supply costs showed greater variation than personnel costs. Other supply costs (3.27), implant cost (2.41), and medication (2.01) had the highest ratios between the highest and lowest-cost procedures (Table I). Implant costs showed the highest average variation across all types of arthroplasties (Table I). Personnel costs between admission and the operating room showed similar variation to costs between PACU and discharge and total personnel costs (Table I). Length of hospital stay ranged from 1.87 days following TAA to 3.14 days after TKA.

Discussion

Implant price was the primary contributor to total inpatient cost for all categories of total joint arthroplasty. The highest-volume procedures, TKA and THA, were the least expensive, driven largely by lower implant purchase prices. Length of stay and personnel costs did not appear to correlate with total cost.

TDABC is an accurate accounting method that helps to identify high-cost resources and opportunities to maximize patient value[7,13]. TDABC is applicable to joint arthroplasty given its scale and discrete episode of care. Consistent with the existing body of literature concerning TSA, THA, and TKA, implant purchase price was the predominant driver of total cost[11,16-18]. Implant cost accounted for at least 40% of overall cost in all types of arthroplasty, showed high variation, and was directly proportional to total inpatient costs. Personnel costs from the preoperative period through the operating room period were proportionately much higher for TEA, but we suspect this finding was due to the paucity of procedures performed, resulting in imperfect and less-efficient preoperative processes. Although other supply costs (consumables) and medication showed similar variation to implant prices between TKA and expensive procedures, they were notably lower than implant prices and constituted <10% of total cost. Implant price therefore has greater potential to drive overall cost and represents the most significant difference between expensive and inexpensive procedures.

The relationship between volume and cost is more complicated. In the present study, increased volume correlated with a considerable decrease in total costs, but this correlation has been refuted in the past[19]. Haas et al. showed that while institutional procedure volume correlated with lower implant prices for TKA, volume had no real relationship with prices for THA[19]. Within our institution, differences in procedure volume on an order-of-magnitude scale may yield higher bargaining power in implant price negotiations, resulting in lower total costs. However, this relationship was not as pronounced for lower-volume procedures. For example, RSA implant costs were 17% higher than TSA implant costs, even though nearly 1.76 times as many RSAs were performed than TSAs. Thus, this trend may not extend beyond an institutional level and may not necessarily imply that higher-volume institutions have the ability to negotiate lower implant prices. Rather, it may reflect the relative paucity of upper-extremity arthroplasty compared with TKA and THA. In 2007, >532,000 TKAs and >244,000 THAs were performed nationwide[4], compared with <25,000 shoulder arthroplasties (anatomic plus reverse) and <3,000 TEAs[5]. As a result, the differences in implant cost in the present study may better represent industry-wide volume and may not directly relate to variation between institutions.

The high variability of implant purchase price suggests ample opportunity for cost savings. Negotiating lower implant prices, particularly for TSA, RSA, and TAA, would result in substantially lowered inpatient costs to the hospital. Previous studies have suggested that large private-practice groups and specialized hospital-physician negotiating committees would increase bargaining power and lower cost[9,20]. Given the lack of cost transparency, however, further research incorporating multiple institutions is required to evaluate the efficiency of these strategies. Outpatient arthroplasty presents another avenue for potential cost savings. Postoperative personnel costs, although proportionately less than implant costs, could be significantly reduced by reducing inpatient stays. Literature has shown that TSA, THA, and TKA are safe and effective in an outpatient setting with appropriate patient selection[21-24]. Carefully selecting patients for outpatient arthroplasty to minimize medical complications could be an effective tool to reduce hospital costs.

The strengths of the present study include the large number of cases analyzed and the uniform methodology employed to analyze arthroplasties performed for multiple joints. To our knowledge, this is the only study to date that has described and analyzed costs with use of accurate, granular data with a single methodology across upper and lower-extremity arthroplasty simultaneously.

The present study has limitations. We were only able to include cost data from a single high-volume orthopaedic specialty hospital, which limits the generalizability of our results to some degree. Recent literature has demonstrated that orthopaedic specialty hospitals have higher operating room efficiency during arthroplasty procedures and thus may exhibit different cost trends than other tertiary referral centers[25]. Furthermore, our data reflect relatively small sample sizes for certain procedures, specifically, TEA and TAA. Ideally, cost analysis would include near-equal numbers of procedures to maximize statistical accuracy. However, the procedure volumes reported here generally resemble the ratio of procedures performed nationwide[5,26]. Few studies have accurately evaluated and compared the costs of TEA and TAA, and thus we believe that our data are valuable[27-30]. Additionally, there were variable numbers of vendors for each procedure type (1, 2, 5, 6, and 4 vendors for TEA, TAA, TKA, THA, and TSA/RSA, respectively). We were unable to provide the breakdown of how many implants were purchased from each respective vendor. Future research should incorporate multiple institutions in order to explore cost patterns on a larger, industry-wide scale. Given the tight regulation of hospital cost-sharing, the current study remains an important model. We were restricted from obtaining individual salaries of each nurse, resident, and fellow and thus did not account for the variable salaries within each position. We do not believe that this factor affected the validity of our results because the cost analysis was broken down on a minute-to-minute scale, thus mitigating the effect of the averaged salaries. Finally, we are only able to report the cost of primary arthroplasties. Further investigation into the relative cost difference between primary and revision arthroplasty would prove enlightening.

In conclusion, inpatient hospital costs for TEA are 65% more expensive than those for TKA. Implant cost was highly variable and appears to be the main driver of cost variation. TKA and THA, which represent more established, higher-volume procedures, cost less overall than TAA and upper-extremity arthroplasty. Understanding the importance of implant price in total inpatient costs is important as hospitals seek new methods to reduce costs and improve value. ■

Note: The authors thank Avant-garde Health for assistance in designing and executing costing protocols.

Michael P. Carducci, BA[1]
Gregory Gasbarro, MD[1,2]
Mariano E. Menendez, MD[3]
Kuhan A. Mahendraraj, BA[1]
David A. Mattingly, MD[1]
Carl Talmo, MD[1]
Andrew Jawa, MD[1]

[1]New England Baptist Hospital, Boston, Massachusetts

[2]Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts

[3]Department of Orthopaedic Surgery, Tufts University School of Medicine, Boston, Massachusetts

Email address for A. Jawa: ajawa@nebh.org

ORCID iD for M.P. Carducci: 0000-0001-5159-6439
ORCID iD for G. Gasbarro: 0000-0003-0844-1057
ORCID iD for M.E. Menendez: 0000-0002-0392-7050
ORCID iD for K.A. Mahendraraj: 0000-0003-4384-4804
ORCID iD for D.A. Mattingly: 0000-0002-8285-459X
ORCID iD for C. Talmo: 0000-0003-0702-5211
ORCID iD for A. Jawa: 0000-0002-1763-390X

References

1. Centers for Medicare & Medicaid Services. National health expenditures 2017 highlights. Accessed 2019 Oct 21. https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/Downloads/highlights.pdf

2. Dobson DaVanzo & Associates. LLC. Medicare payment bundling: insights from claims data and policy implications. 2012 Oct 26. Accessed 2019 Oct 21. https://www.aha.org/system/files/2018-11/ahaaamcbundlingreport.pdf

3. Kurtz SM, Ong KL, Schmier J, Zhao K, Mowat F, Lau E. Primary and revision arthroplasty surgery caseloads in the United States from 1990 to 2004. J Arthroplasty. 2009 Feb;24(2):195-203. Epub 2008 Apr 15.

4. Sloan M, Premkumar A, Sheth NP. Projected volume of primary total joint arthroplasty in the U.S., 2014 to 2030. J Bone Joint Surg Am. 2018 Sep 5;100(17):1455-60.

5. Day JS, Lau E, Ong KL, Williams GR, Ramsey ML, Kurtz SM. Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. J Shoulder Elbow Surg. 2010 Dec;19(8):1115-20. Epub 2010 Jun 15.

6. Kim SH, Wise BL, Zhang Y, Szabo RM. Increasing incidence of shoulder arthroplasty in the United States. J Bone Joint Surg Am. 2011 Dec 21;93(24):2249-54.

7. Akhavan S, Ward L, Bozic KJ. Time-driven activity-based costing more accurately reflects costs in arthroplasty surgery. Clin Orthop Relat Res. 2016 Jan;474(1):8-15.

8. Chen A, Sabharwal S, Akhtar K, Makaram N, Gupte CM. Time-driven activity based costing of total knee replacement surgery at a London teaching hospital. Knee. 2015 Dec;22(6):640-5. Epub 2015 Jul 30.

9. DiGioia AM 3rd, Greenhouse PK, Giarrusso ML, Kress JM. 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 Jan;31(1):1-6. Epub 2015 Jul 11.

10. Haas DA, Kaplan RS. Variation in the cost of care for primary total knee arthroplasties. Arthroplast Today. 2016 Sep 30;3(1):33-7.

11. Menendez ME, Lawler SM, Shaker J, Bassoff NW, Warner JJP, Jawa A. Time-driven activity-based costing to identify patients incurring high inpatient cost for total shoulder arthroplasty. J Bone Joint Surg Am. 2018 Dec 5;100(23):2050-6.

12. Kaplan RS, Porter ME. How to solve the cost crisis in health care. Harv Bus Rev. 2011 Sep;89(9):46-52: 54: 56-61 passim.

13. Kaplan RS, Anderson SR. Time-driven activity-based costing. Harv Bus Rev. 2004 Nov;82(11):131-8: 150.

14. Najjar PA, Strickland M, Kaplan RS. Time-driven activity-based costing for surgical episodes. JAMA Surg. 2017 Jan 1;152(1):96-7.

15. Keel G, Savage C, Rafiq M, Mazzocato P. Time-driven activity-based costing in health care: A systematic review of the literature. Health Policy. 2017 Jul;121(7):755-63. Epub 2017 May 10.

16. Navathe AS, Troxel AB, Liao JM, Nan N, Zhu J, Zhong W, Emanuel EJ. Cost of joint replacement using bundled payment models. JAMA Intern Med. 2017 Feb 1;177(2):214-22.

17. Robinson JC, Pozen A, Tseng S, Bozic KJ. Variability in costs associated with total hip and knee replacement implants. J Bone Joint Surg Am. 2012 Sep 19;94(18):1693-8.

18. Palsis JA, Brehmer TS, Pellegrini VD, Drew JM, Sachs BL. The cost of joint replacement: comparing two approaches to evaluating costs of total hip and knee arthroplasty. J Bone Joint Surg Am. 2018 Feb 21;100(4):326-33.

19. Haas DA, Bozic KJ, DiGioia AM, Song Z, Kaplan RS. Drivers of the variation in prosthetic implant purchase prices for total knee and total hip arthroplasties. J Arthroplasty. 2017 Feb;32(2):347-350.e3. Epub 2016 Aug 16.

20. Courtney PM, West ME, Hozack WJ. Maximizing physician-hospital alignment: lessons learned from effective models of joint arthroplasty care. J Arthroplasty. 2018 Jun;33(6):1641-6. Epub 2018 Jan 31.

21. Brolin TJ, Mulligan RP, Azar FM, Throckmorton TW. Neer Award 2016: Outpatient total shoulder arthroplasty in an ambulatory surgery center is a safe alternative to inpatient total shoulder arthroplasty in a hospital: a matched cohort study. J Shoulder Elbow Surg. 2017 Feb;26(2):204-8. Epub 2016 Aug 31.

22. Brolin TJ, Cox RM, Zmistowski BM, Namdari S, Williams GR, Abboud JA. Surgeons' experience and perceived barriers with outpatient shoulder arthroplasty. J Shoulder Elbow Surg. 2018 Jun;27(6S)(Supplement):S82-7.

23. Kim KY, Feng JE, Anoushiravani AA, Dranoff E, Davidovitch RI, Schwarzkopf R. Rapid discharge in total hip arthroplasty: utility of the outpatient arthroplasty risk assessment tool in predicting same-day and next-day discharge. J Arthroplasty. 2018 Aug;33(8):2412-6. Epub 2018 Mar 17.

24. Berend ME, Lackey WG, Carter JL. Outpatient-focused joint arthroplasty is the future: the Midwest Center for Joint Replacement experience. J Arthroplasty. 2018 Jun;33(6):1647-8. Epub 2018 Feb 9.

25. Padegimas EM, Hendy BA, Chan WW, Lawrence C, Cox RM, Namdari S, Lazarus MD, Williams GR, Ramsey ML, Horneff JG. The effect of an orthopedic specialty hospital on operating room efficiency in shoulder arthroplasty. J Shoulder Elbow Surg. 2019 Jan;28(1):15-21. Epub 2018 Sep 18.

26. Jiang JJ, Schipper ON, Whyte N, Koh JL, Toolan BC. Comparison of perioperative complications and hospitalization outcomes after ankle arthrodesis versus total ankle arthroplasty from 2002 to 2011. Foot Ankle Int. 2015 Apr;36(4):360-8. Epub 2014 Oct 30.

27. Zhou H, Orvets ND, Merlin G, Shaw J, Dines JS, Price MD, Eichinger JK, Li X. Total elbow arthroplasty in the United States: evaluation of cost, patient demographics, and complication rates. Orthop Rev (Pavia). 2016 Mar 31;8(1):6113.

28. Nwachukwu BU, McLawhorn AS, Simon MS, Hamid KS, Demetracopoulos CA, Deland JT, Ellis SJ. Management of end-stage ankle arthritis: cost-utility analysis using direct and indirect costs. J Bone Joint Surg Am. 2015 Jul 15;97(14):1159-72.

29. Gross CE, Scott D, Mather RC, Nunley JA. Effect of facility on operative costs of total ankle arthroplasties. J Surg Orthop Adv. 2018 Winter;27(4):321-4.

30. Federer AE, Mather RC 3rd, Ramsey ML, Garrigues GE. Cost-effectiveness analysis of total elbow arthroplasty versus open reduction-internal fixation for distal humeral fractures. J Shoulder Elbow Surg. 2019 Jan;28(1):102-11.