Time-Driven Activity-Based Costing to Identify Patients Incurring High Inpatient Cost for Total Shoulder Arthroplasty

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Background: As payment models shift toward a focus on value, an accurate understanding of surgical costs and preoperative correlates of high-cost patients is important for effective implementation of cost-saving strategies. This study used time-driven activity-based costing (TDABC) to explore inpatient cost of total shoulder arthroplasty (TSA) and to identify preoperative characteristics of high-cost patients.

Methods: Using TDABC, we calculated the cost of inpatient care for 415 patients undergoing elective primary TSA between 2016 and 2017. Patients in the top decile of cost were defined as high-cost patients. Multivariable logistic regression modeling was employed to determine preoperative characteristics (e.g., demographics, comorbidities, American Society of Anesthesiologists [ASA] score, and American Shoulder and Elbow Surgeons [ASES] score) associated with high-cost patients.

Results: Implant purchase price was the main driver (57%) of total inpatient costs, followed by personnel cost from patient check-in through the time in the operating room (20%). There was a 1.3-fold variation in total cost between patients in the 90th percentile for cost and those in the 10th percentile; the widest cost variation was in personnel cost from the post-anesthesia care unit through discharge (2.5-fold) and in medication cost (2.4-fold). High-cost patients were more likely to be women and chronic opioid users and to have diabetes, depression, an ASA score of ≥3, a higher body mass index (BMI), and a lower preoperative ASES score than non-high-cost patients. After multivariable adjustment, the 3 predictors of high-cost patients were female sex, an ASA score of ≥3, and a lower ASES score. Total inpatient cost correlated strongly with the length of the hospital stay but did not correlate with operative time.

Conclusions: Our study provides actionable data to contain costs in the perioperative TSA setting. From the hospital's perspective, efforts to reduce implant purchase prices may translate into rapid substantial cost savings. At the patient level, multidisciplinary initiatives aimed at reducing length of stay and controlling medication expenses for patients at risk for high cost (e.g., infirm women with poor preoperative shoulder function) may prove effective in narrowing the existing patient-to-patient variation in costs.

Level of Evidence: Economic and Decision Analysis Level IV. See Instructions for Authors for a complete description of levels of evidence.

As payment models shift toward a focus on value and the financial risk of providing services falls on hospitals and providers, optimizing cost and resource utilization for elective orthopaedic surgical procedures has become a major priority. One compelling strategy for cost containment is focusing on high-need, high-cost surgical patients[1,2], but questions remain regarding how to determine surgical costs accurately.

Traditional hospital-cost-measurement approaches using either cost-to-charge ratios or relative value units are often inaccurate and use arbitrary allocations that provide little transparency in the actual care processes[3,4]. Time-driven

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activity-based costing (TDABC) is an innovative approach to measure cost more accurately by estimating the quantity of time and the cost per unit of time of each resource (e.g., equipment and personnel) used across an episode of care[5,6]. For instance, if a staff member spends 20 minutes with a patient, and the cost of that staff member's time is $60 per hour, then the cost of that patient interaction is $20.

Despite growing interest in this accounting approach, its adoption in orthopaedic surgery has been limited and confined to lower-limb arthroplasty[4,7-10]. In particular, little is known about TDABC in the context of total shoulder arthroplasty (TSA), the demand for which has grown more than twice as fast as that for hip and knee replacements over the past decade[11-13]. Two recent studies of lower-limb arthroplasty showed that TDABC was more accurate in reflecting true costs than traditional accounting methods[4,10]. However, to our knowledge, no study has employed TDABC methodology to identify high-cost orthopaedic surgery populations.

Using TDABC, we sought to (1) examine how different aspects of inpatient care account for total costs for patients undergoing TSA, (2) identify preoperative patient characteristics associated with high inpatient cost, and (3) evaluate the relationship of inpatient cost with commonly used process measures including length of hospital stay and operative time[14,15].

Materials and Methods

Sample and Study Design

Following institutional review board approval, we used our prospectively collected database to identify all patients who had elective primary TSA (anatomic or reverse) performed by a single fellowship-trained shoulder surgeon between January 2016 and November 2017. To achieve a more homogeneous sample, we decided a priori to exclude patients whose indication for surgery was traumatic and those who underwent revision surgery. We employed TDABC methodology[16,17] to accurately determine the inpatient episode-of-care cost of TSA.

Time-Driven Activity-Based Costing

TDABC is an emerging approach for measuring costs across an episode of care[6]. It starts by outlining, through process maps (see Appendix), all of the clinical and administrative steps of the care process. It requires estimates of 2 parameters: the quantity of time and the cost per unit of each resource (e.g., equipment and personnel) used to treat patients[5]. For instance, a nurse's cost per minute is calculated by dividing the total annual compensation by the total number of minutes that the nurse is available for clinical care[5]. Total episode costs are then calculated by multiplying the total number of minutes used for each resource by the per-minute costs and summing across all resources used during the episode.

Our study focused on inpatient costs associated with TSA from patient check-in on the day of surgery through room cleaning on the day of hospital discharge. Process maps were developed for each phase of care: preoperative, intraoperative, and postoperative (see Appendix). The present analysis focused on direct personnel and consumable supply (e.g., implant) costs. We considered the actual purchase prices to be the costs for consumable supplies. The same 2 implants were used for all anatomic and reverse TSAs. Indirect costs (e.g., human resources and billing) were excluded, as assigning these costs accurately would have required exhaustive cost modeling and analysis for every indirect and overhead cost category in our institution. Costs were organized into predefined categories: implant, medications, other supplies (e.g., operating room consumables), and personnel cost (preoperative through operating room, and post-anesthesia care unit [PACU] through discharge).

The costs were calculated using software and guidance from Avant-garde Health with input from the administrative director for orthopaedic surgery, financial analysts, and physicians at the hospital. The software from Avant-garde Health processed patient-level electronic health record data regarding demographics, surgical procedure, staff-entered time stamps throughout the hospital stay, care delivered (e.g., physical therapy), and supplies and drugs utilized (and their purchase prices). These patient-level data then underwent a cleaning and integrity check process to look for anomalies, such as inconsistent time stamps and supply prices that were outside of typical ranges. Data points that failed these data integrity checks were removed. The data were then run through a TSA care process flow model. This care process flow model included information on inpatient care processes that are not stored in the patient-level data, such as the personnel involved and the time spent in each step of the care process. The care process model was developed through a combination of Avant-garde's previous work in TSA, direct observations of the clinical workflow, and a series of interviews with different clinicians and staff involved in the care cycle. The average duration of each of the care processes (e.g., patient check-in and transfer from the operating room to the PACU), as shown in the Appendix, was estimated through direct observations and interviews with the involved staff. For more variable processes such as operative time and length of hospitalization, the duration was obtained from manually-entered time stamps in the electronic health record.

Variables

We gathered data on various patient characteristics such as age, sex, previous shoulder surgery, the American Society of Anesthesiologists (ASA) score, body mass index (BMI), and several comorbidities that are prospectively collected in our registry, including diabetes, preoperative chronic opioid use (defined as taking opioids daily before surgery), hypertension, hypercholesterolemia, depression, thyroid disease, and rheumatoid arthritis. Comorbidities were self-reported by patients. We also included the preoperative American Shoulder and Elbow Surgeons (ASES) score[18], which is routinely collected by our research staff during the preoperative office visit. The ASES score contains both physician-rated and patient-rated sections, and the final total score (on a 100-point scale) is weighted 50% for pain and 50% for function, with higher scores indicating better outcomes[19].

Patient-level timing data throughout the hospital stay were extracted from the electronic medical record system to

TABLE I Bivariate Analysis of Characteristics of the Study Population

		High-Cost Patient (Top Decile)		
Parameter	All Patients	Yes	No	P Value*
Total†	415 (100)	40 (9.6)	375 (90.4)	
Age‡ *(yr)*	68.8 ± 8.4	66.8 ± 10.8	69.1 ± 8.1	0.19
Sex†				**0.001**
Female	253 (61.0)	34 (85.0)	219 (58.4)	
Male	162 (39.0)	6 (15.0)	156 (41.6)	
ASA score†,§				**<0.001**
≤2	318 (77.4)	19 (48.7)	299 (80.4)	
≥3	93 (22.6)	20 (51.3)	73 (19.6)	
BMI‡ *(kg/m²)*	30.8 ± 6.3	33.6 ± 8.8	30.5 ± 5.9	**0.038**
Comorbid conditions†				
Preoperative opioid use	68 (16.4)	13 (32.5)	55 (14.7)	**0.004**
Diabetes	58 (14.0)	12 (30.0)	46 (12.3)	**0.002**
Hypertension	247 (59.5)	25 (62.5)	222 (59.2)	0.69
Hypercholesterolemia	163 (39.3)	15 (37.5)	148 (39.5)	0.81
Depression	104 (25.1)	16 (40.0)	88 (23.5)	**0.022**
Thyroid disease	86 (20.7)	9 (22.5)	77 (20.5)	0.77
Rheumatoid arthritis	17 (4.1)	0	17 (4.5)	0.39
Preoperative ASES score‡	34.1 ± 16.5	25.9 ± 15.2	35 ± 16.4	**0.001**
Prior shoulder surgery†	132 (31.8)	11 (27.5)	121 (32.3)	0.54
Procedure type†				0.54
Anatomic TSA	121 (29.2)	10 (25.0)	111 (29.6)	
Reverse TSA	294 (70.8)	30 (75.0)	264 (70.4)	

*The values in bold indicate a significant difference. †The values are given as the number of patients, with the percentage in parentheses. ‡The values are given as the mean and the standard deviation. §ASA scores were missing for 4 patients.

calculate operative time (time from incision to closure) and length of hospital stay.

Statistical Analysis

Because of the confidentiality of internal hospital cost data, all costs are being presented as percentages or as indexed values rather than actual dollars. To assess patient-level variation, we determined costs for patients in the 90th and 10th percentiles of total cost, and used the ratio of the 90th to the 10th percentile as a measure of variation[9].

Consistent with previous research[1,20], we defined patients in the top decile of total cost as high-cost patients. To compare patient characteristics between high-cost and non-high-cost patients, we used Pearson chi-square or Fisher exact (for cell sizes of <5) tests for categorical variables and independent-samples t tests for continuous variables. Continuous variables are presented as the mean and standard deviation, and categorical variables are reported as frequencies and percentages.

To minimize confounding, variables with a p value of <0.05 in bivariate analysis were inserted into multiple logistic regression analysis to identify which preoperative patient characteristics were independently associated with high inpatient cost for TSA. We entered all variables into the model simultaneously, without further selection. Results are reported as odds ratios (ORs) with 95% confidence intervals (CIs). We used the area under the receiver operating characteristic (ROC) curve to assess model discrimination and the Hosmer-Lemeshow test to evaluate model calibration.

We employed Pearson correlation coefficients (r) to determine the relationship between total inpatient cost and commonly used process measures, including length of hospital stay and operative time[14,15].

Statistical tests were 2-sided with $p < 0.05$ denoting significance.

Patient Characteristics (Table I)

The 415 patients in our study population included 253 women (61%) and 162 men, with a mean age (and standard deviation) of 69 ± 8 years and a mean preoperative ASES score of 34 ± 17. Most patients (77%) had an ASA score of ≤2. Nearly one-third (32%) had had previous shoulder surgery. The 3 most prevalent comorbidities were hypertension (60%), hypercholesterolemia (39%), and depression (25%). The prevalence of preoperative chronic opioid use was 16%. Reverse TSA was performed in

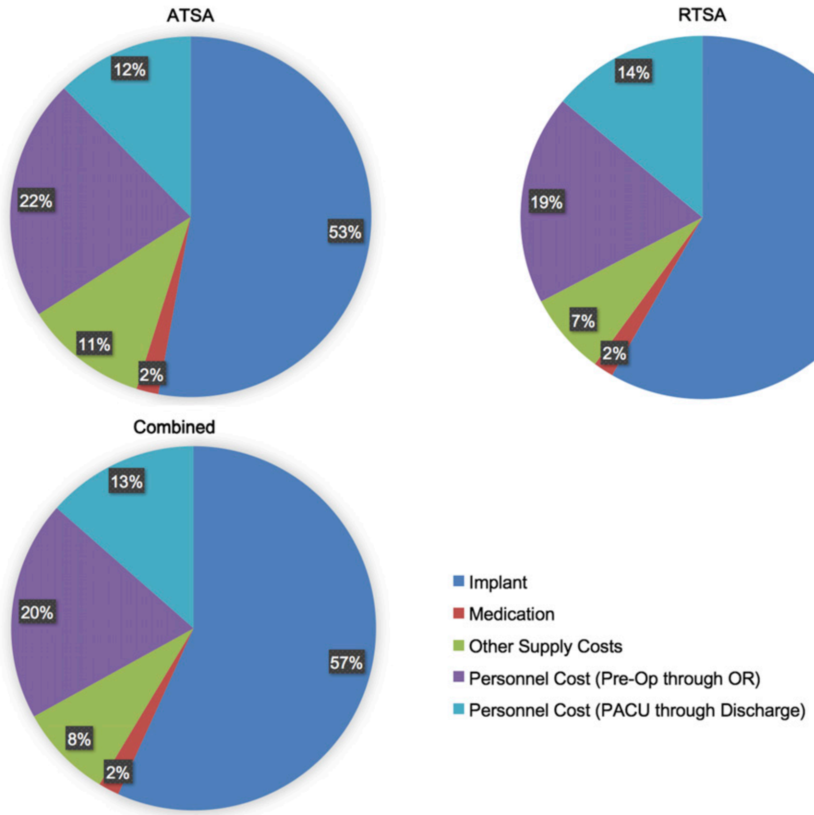

Fig. 1

Pie charts showing cost categories as a percentage of the overall inpatient cost for anatomic TSA (ATSA), reverse TSA (RTSA), and both as determined using TDABC costing. OR = operating room.

71% of the patients, and anatomic TSA was done in the remaining 29%.

Results

Overall, there was a 1.3-fold variation (anatomic TSA: 1.4-fold; reverse TSA: 1.2-fold) in total cost between patients in the 90th percentile and those in the 10th percentile for cost. Implant cost accounted for over half (57%) of total inpatient costs (anatomic TSA: 53%; reverse TSA: 58%; Fig. 1). Personnel cost from patient registration through the operating room accounted for 20% of total costs (anatomic TSA: 22%; reverse TSA: 19%), while personnel cost from the PACU through discharge represented 13% of total costs (anatomic TSA: 12%; reverse TSA: 14%). The widest cost variation

TABLE II Multivariable Logistic Regression Analysis of Preoperative Factors Associated with High-Cost TSA Inpatient Care*

Predictor	OR	95% CI Lower	95% CI Upper	P Value†
Female sex (reference: male)	3.66	1.41	9.54	**0.008**
ASA score ≥3 (reference: ≤2)	2.97	1.31	6.74	**0.009**
Preoperative opioid use	1.93	0.86	4.32	0.109
Depression	1.34	0.63	2.89	0.448
Diabetes	1.75	0.71	4.33	0.224
BMI, per 1-unit increase	1.03	0.98	1.09	0.258
Preoperative ASES score, per 1-unit increase	0.97	0.95	0.99	**0.039**

*Area under the ROC curve = 0.79 (95% CI = 0.72 to 0.86), Nagelkerke R^2 = 0.22, and p value for Hosmer and Lemeshow test = 0.33. †The values in bold indicate a significant difference.

between patients in the 90th and 10th percentiles for total cost was in personnel cost from the PACU through discharge (2.5-fold) and in medication cost (2.4-fold), while the least variation was found in implant cost (1.3-fold) and personnel cost from the preoperative phase of care through the operating room (1.4-fold).

High-cost patients were more likely to be women (85% versus 58%, p = 0.001) and chronic opioid users (33% versus 15%, p = 0.004) and to have diabetes (30% versus 12%, p = 0.002), depression (40% versus 24%, p = 0.022), an ASA score of ≥3 (51% versus 20%, p < 0.001), a lower preoperative ASES score (26 ± 15 versus 35 ± 16, p = 0.001), and a higher BMI (34 ± 9 versus 31 ± 6 kg/m^2, p = 0.038) than non-high-cost patients (Table I). After adjustment for potential confounding effects in multivariable modeling (Table II), the preoperative patient characteristics independently associated with high inpatient costs were female sex (OR = 3.66, 95% CI = 1.41 to 9.54, p = 0.008) versus male sex, an ASA score of ≥3 (OR = 2.97, 95% CI = 1.31 to 6.74, p = 0.009) versus an ASA score of ≤2, and a lower ASES score (OR = 0.97 per 1-unit increase, 95% CI = 0.95 to 0.99, p = 0.039).

There was a strong correlation between length of hospital stay and total inpatient cost (r = 0.64, p < 0.001); for instance, there was a 12% increase in costs from postoperative day 1 to 2. The mean length of stay was 2.2 ± 0.9 days overall, 3.7 ± 1.0 days for high-cost patients, and 2.1 ± 0.7 days for non-high-cost patients (p < 0.001). There was no correlation between operative time and total cost (r = 0.16, p = 0.39).

Discussion

In times of intense scrutiny of health-care costs, TDABC is gaining traction as an accurate method to estimate costs. Because of the growing interest in this accounting approach and burgeoning demand for TSA[11-13,21], it seems timely to apply TDABC for this major orthopaedic procedure. As providers become increasingly cost-conscious, an accurate understanding of costs and preoperative correlates of high-cost patients is important for effective implementation of cost-saving strategies. In this context, we used TDABC to explore the inpatient cost of TSA and to determine preoperative characteristics of the patients for whom the inpatient care was the most costly. Additionally, we evaluated the association of cost with length of hospital stay and operative time.

The principal strengths of this study include its relatively large sample size, the use of clinical rather than claims data, and the application of the emerging TDABC methodology to explore surgical costs and identify high-cost patients. Nonetheless, our analysis was subject to several limitations that generate questions for future research. First, this study was conducted at a large urban orthopaedic specialty hospital serving predominantly white patients in the northeastern United States, and the results may lack generalizability[22]. Second, given that all procedures were performed by a single surgeon, we were unable to examine physician characteristics (e.g., technical skill, case volume, and interpersonal communication skills) influencing cost. Third, our TDABC approach used aggregated patient data from the typical care pathway, which reflects an assumption that postoperative recovery is without complications. As such, the calculation of standard deviations for the time spent in each step of the care process was not possible. We did not specifically measure time allotted to patient care with time stamps or stopwatches. Although it is likely that our estimates minimized the variation in total cost between patients, this approach is consistent with the original description of the TDABC methodology. Moreover, these types of assumptions drive little of the cost compared with more variable processes such as operative time and length of hospitalization—which we estimated using manually entered time stamps in the electronic health record. Fourth, because this was a retrospective review of a prospectively collected registry, the data collection protocol was not specifically designed for this study. Thus, we were unable to assess some potentially important patient factors affecting cost, such as health literacy and patient activation—2 increasingly recognized concepts that have been linked to health-care resource use[23,24]. Fifth, as our data were limited to the inpatient setting, we were unable to calculate post-acute-care costs. However, compared with lower-limb arthroplasty, post-discharge care following TSA seems to play a less important role in total episode-of-care costs, as fewer patients require post-acute rehabilitation care. Finally, to achieve higher-value care for patients undergoing TSA, TDABC costs must be linked to patient experience, quality of life, and functional outcomes, which is the object of our future research. Nevertheless, this study is an important step toward introducing clarity into the cost conundrum of TSA and will hopefully stimulate further research into this increasingly important topic.

Consistent with the hip and knee arthroplasty literature[25-27], we observed that implant purchase price was the main cost driver of TSA, accounting for over half (57%) of total inpatient spending. There is a paucity of data regarding the inpatient cost of TSA, but it is likely that traditional accounting methods underestimate the role of implant cost in total spending as they tend to overestimate personnel costs. Our finding suggests that efforts to reduce TSA implant cost may be an important way to achieve substantial hospital savings rapidly. Indeed, the wide variation in joint arthroplasty implant purchase prices across hospitals suggests that there is ample opportunity for cost reduction[27]. Along these lines, Haas and colleagues[28] recently noted that hospitals using a joint committee of hospital administrators and surgeons to negotiate prices with vendors paid 17% less for implants than institutions without a joint purchasing committee. Our study also showed that the increased inpatient cost for the highest-cost patients was, to a large extent, attributable to higher medication cost and personnel cost from the PACU through discharge. While directly decreasing medication and personnel costs may not be feasible, indirectly lowering costs by reducing length of stay has come into focus as an area for improvement[29].

Our study identified several preoperative patient characteristics associated with high-cost inpatient care for TSA. The observation that women were nearly 4 times more likely to be among the highest-cost patients adds to the current body of knowledge showing that women experience longer hospital stays and worse functional outcomes following TSA[29,30]. There may be nociceptive and psychosocial differences attributable to sex[31] that warrant further research in the perioperative TSA setting. We observed that greater infirmity—assessed with the ASA score—was linked to high-cost inpatient care, which is consistent with previous research suggesting that the ASA score is useful in predicting readmission and resource use after TSA[32,33]. Our finding that lower preoperative ASES scores were predictive of high-cost inpatient care is particularly relevant with the growing emphasis on value, and underscores the importance of incorporating patient-reported outcome measures as part of routine clinical care. Along these lines, Jacobs and colleagues[34] recently showed that patient dissatisfaction following anatomic TSA was related to lower preoperative ASES scores. In our study, preoperative opioid use was not retained as an independent predictor of high-cost patients, although this may be due to a type-II error as the association showed borderline significance ($p = 0.11$); we encourage the performance of larger confirmatory studies. Importantly, greater BMI was not independently associated with high-cost inpatient care. The latter finding may make shoulder surgeons less reluctant to operate on patients with a high BMI and is consistent with previous studies suggesting that BMI exerts a minimal impact on outcomes after TSA[35,36].

It is not surprising that length of hospital stay—a common proxy for episode resource use—correlated strongly with total inpatient cost of TSA. While one may assume that extended stays are largely attributable to patient illness or complications, a study of >22,000 general surgery patients across 199 hospitals showed that much of the variation in length of stay remained unexplained after accounting for such factors and therefore most likely represented practice style differences. Although this issue requires formal investigation, it is our impression that common reasons for patients to stay an additional day in the hospital after TSA are pain-related and social-support-related issues, both potentially responsive to quality improvement initiatives. Strategies to reduce length of stay after TSA can start the first moment surgery is considered, by setting realistic expectations about pain management (e.g., "Surgery hurts . . . let's plan how to manage your pain after surgery.") and ensuring adequate postoperative social support (e.g., "Can you try to arrange for a family member or close friend to stay at home with you for a few days after surgery?"). We found that operative time did not correlate with inpatient costs. While increased surgical duration may be linked to a higher risk for post-discharge complications such as infection[37], its influence on inpatient costs seems to be more limited.

In conclusion, this study employed TDABC methodology to explore the inpatient cost of TSA and identify patient characteristics associated with high cost. From the hospital's perspective, efforts to reduce implant purchase prices may translate to substantial cost savings. From the patient's perspective, multidisciplinary initiatives aimed at reducing the length of hospital stay and controlling medication expenses for patients at risk for high cost (e.g., infirm women with poor preoperative shoulder function) may prove effective in narrowing the existing patient-to-patient variation in costs.

Appendix

eA Tables showing TDABC process maps are available with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/E972). ■

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