RESEARCH ARTICLE

Predictors of Higher Costs Following Reverse Total Shoulder Arthroplasty

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Abstract

Objectives: The rising popularity of reverse total shoulder arthroplasties (RTSA) demands attention to its growing costs on the healthcare system, especially with the implementation of bundled payments. Charges associated with patients' inpatient stays can be mitigated with a better understanding of the drivers of cost following RTSA. In this study, we evaluate potential pre-operative and post-operative factors associated with higher inpatient costs following RTSA.

Methods: We identified 59,925 patients who underwent RTSA using the National Inpatient Sample between 2016 and 2019. Total inpatient hospital charges were collected, and patients were divided into "normal cost" or "high cost" groups. The high cost group was defined as patients with total costs greater than the 75th percentile. Univariate and multivariate analyses were performed on pre-operative demographic and comorbidity variables as well as post-operative surgical and medical complications to predict factors associated with higher costs. T-tests and Chi-squared tests were performed, and odds ratios were calculated.

Results: The mean total charges were $141.213.93 in the high cost group and $59,181.94 in the normal cost group. Following multivariate analysis, non-white patients were associated with higher costs by 1.31-fold (P<0.001), but sex and age were not. Cirrhosis and non-elective admission had higher odds of higher costs by 1.56-fold (P<0.001) and 3.13-fold (P<0.001), respectively. Among surgical complications, there were higher odds of high costs for periprosthetic infection by 2.43-fold (P<0.001), periprosthetic mechanical complication by 1.28-fold (P<0.001), and periprosthetic fracture by 1.56-fold (P<0.001). Medical complications generally had higher odds of high costs than surgical complications, with deep vein thrombosis having nearly five times (P<0.001) and myocardial infarction almost four times (P<0.001) higher odds of high inpatient costs.

Conclusion: Post-operative medical complications were the most predictive factors of higher cost following RTSA. Pre-operative optimization to prevent infection and medical complications is imperative to mitigate the economic burden of RTSA's.

Level of evidence: III

Keywords: Complications, Costs, Predictor, Reverse total shoulder arthroplasty

Introduction

Reverse total shoulder arthroplasty (RTSA) has become increasingly popular over the past decade, with RTSA becoming more commonly performed in lieu of anatomic total shoulder arthroplasty and shoulder hemiarthroplasty for arthritis and fracture.[1,2] Alongside the popularity of RTSA has been the rising associated hospital charges over the past 3 decades in both rural and urban settings.[3] The Patient Protection and Affordable Care Act of 2010 implemented bundled payments for services, including for surgeries where all charges associated with the surgical encounter are bundled into a single shared fee. As healthcare reimbursement is shifting towards bundled payment models, there is a greater emphasis on understanding costs to develop value-based reimbursement strategies for healthcare systems. Thus, the rise in demand and volume of RTSA warrants

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investigation into its cost utilization and value of care.[4]

Previous studies assessing factors associated with the cost of shoulder arthroplasty have found implant cost to be the largest contributor.[4-8] However, implant costs have been shown to have wide variability among hospitals and can be individually negotiated with hospital contracts.[6,9] These, however, do not account for charges amassed following surgery in the inpatient setting. Following operative costs, inpatient costs have been identified as the second highest contributor to total costs for shoulder arthroplasty, which may account for 24% of the total bundled fee.[10] Thus, it is important to identify addressable factors that may contribute to higher costs in the inpatient setting.

While studies have evaluated the economic burden of shoulder arthroplasty, many did not separate RTSA and anatomic total shoulder arthroplasty (ATSA).[3,8,10,11] Meanwhile, other studies analyzing costs were performed at a single institution and lack generalizability.[5,7,10,12] There is evidence to support high variability in the costs of shoulder arthroplasty among institutions and geographic areas.[3,6,13] Davis *et al*[3] examined predictors of increased hospital charges following ATSA with a national database, but in patients from 1993 to 2010, prior to the implementation of the Affordable Care Act and prior to the recent rise in RTSA. Information representative of the general United States population regarding contributors to higher inpatient costs specifically following reverse total shoulder arthroplasty is lacking.

In this study, we assess a nationally representative sample of patients to identify pre-operative and post-operative factors associated with higher costs following reverse total shoulder arthroplasty.

Materials and Methods

The National Inpatient Sample (NIS) Database was used for this study and we collected data from patients between 2016 and 2019. It is the largest publicly available, all-payer database of patient information in the United States with over seven million inpatient hospital stays, and involves approximately 20% of the hospitals in the country. The data is verified through independent contractors that compare database values to standardized values as quality control. The NIS database contains patient demographic information, length of stay (LOS), hospital charges, comorbidities, complications, and other perioperative variables.

This study was exempt from Institutional Review Board (IRB) approval because the data from the NIS is de-identified and publicly available. Diagnoses were identified using the International Classification of Diseases, Tenth Revision, Clinical Modification/Procedure Coding System (ICD-10-CM/PCS). Patients were divided into two groups, normal cost and high cost. The high cost group was defined as patients with total costs greater than the 75th percentile, while normal costs were those with total costs less than the 75th percentile. Two categories of explanatory variables were studied: 1. pre-operative factors including demographics and comorbidities, and 2. post-operative complications including medical and surgical. Patient demographics, hospital admission status, length of stay, total costs, medical comorbidities, and post-operative complications were recorded. Sex in our study refers to the binary categorization assigned at birth as male or female. Comorbidities and complications were identified using ICD-10 diagnosis codes. Medical comorbidities included obesity, tobacco use disorder, diabetes, cirrhosis, Parkinson's disease, chronic kidney disease (CKD), dialysis status, history of solid organ transplant, systemic lupus erythematosus (SLE), ulcerative colitis, and sickle cell disease. Post-operative complications included wound dehiscence, superficial surgical site infection (SSI), periprosthetic joint infection (PJI), periprosthetic mechanical complication, periprosthetic dislocation, periprosthetic fracture, deep venous thrombosis (DVT), pulmonary embolism (PE), blood transfusion, blood loss anemia, pneumonia, myocardial infarction, acute renal failure, and mortality [Appendix].

The SPSS version 27.0 (IBM, Armonk, NY, USA) was used for statistical analysis. Independent T-test of unequal variances and Chi-squared tests were used for numerical and binomial variables, respectively. Fischer's exact test was applied for incidences less than five. Odds ratios and corresponding 95% confidence intervals for predictive factors were calculated as a ratio of incidence between the high cost and normal cost groups. Variables that were significantly associated with costs on univariate analysis underwent further multivariate analyses. Statistical significance was defined as a *P-value* of less than 0.05.

Results

There were 59,925 patients who underwent RTSA between 2016 and 2019. The mean total charges for all patients were $79,687.87 with a standard deviation of $48,782.57. The 75th percentile of total charges was $94,955.00. The mean total charges of the high cost group were $141.213.93, with a standard deviation of $59,343.71. The mean total charges of the normal cost group were $59,181.94, with a standard deviation of $17.805.42. Patients in the higher cost group had significantly longer LOS, with a mean of 2.65 days and a standard deviation of 1.27 days than the normal cost group, which had a mean LOS of 1.65 days and a standard deviation of 1.29 days (*P*<0.001). There was no difference in the age of admission between the two groups, with the high cost and normal cost groups having a mean age of 71.4 and 71.3 years of age, respectively [Table 1].

On univariate analysis, patients who were non-white, female, or at the extremes of age for RTSA (younger than 60 years old and older than 90 years old) were associated with higher inpatient costs. Non-elective admission status was also associated with higher costs. The comorbidities associated with higher costs were cirrhosis and chronic kidney disease. Most postoperative complications related to the prosthetic implant or medical-related were associated with higher hospital costs, except for wound dehiscence, superficial SSI, and periprosthetic dislocation [Table 2].

On multivariate analysis, patients who were non-white were associated with higher costs (OR 1.31, 95% CI (1.25-1.38), *P*<0.001); but sex and age were no longer associated with higher costs. Liver cirrhosis was associated with higher costs (OR 1.56, 95% CI (1.22-1.98), *P*<0.001) along with non-elective admission status at three-fold odds (OR 3.13, 95% CI (2.94-3.33), *P*<0.001), but a diagnosis of tobacco use disorder was associated with normal costs (OR

0.75, 95% CI (0.72-0.80), *P*<0.001). As for postoperative surgical complications, PJI, periprosthetic mechanical complications, and periprosthetic fracture were all significantly associated with higher costs. PJI was most predictive with approximately two-and-a-half higher odds of high costs (OR 2.43, 95% CI (1.96-3.02), *P*<0.001). Regarding post-operative medical complications, having a DVT had nearly five times the odds of higher cost (OR 4.88, 95% CI (2.60-9.16), *P*<0.001) while myocardial infarction had almost four times the odds of higher costs (OR 3.97, 95% CI (1.80-8.79), *P*<0.001) [Table 3].

Table 1. Comparison of normal cost group and high cost group

	Normal cost	High cost	Mean Difference	95% CI Lower	95% CI Upper	*P*-value
Patients (%)	44721 (74.5%)	15201 (25.5%)	na	na	na	na
Mean cost (SD)	$59,181.94 ($17,805.42)	$141,213.93 (59,343.71)	$80,031.99	$81,065.03	$82,998.95	<0.001
LOS (days)	1.65 (1.29)	2.65 (1.27)	1.00	0.96	1.06	<0.001
Age at admission (years)	71.37 (8.52)	71.31 (8.96)	-0.06	-0.23	0.10	0.47

LOS, Length of Stay. P ≤ 0.05 statistically significant (in bold)

Table 2. Univariate comparison between patients in the normal cost group and those in the high cost group

Variable	Normal cost, n(%); n=44621	High cost, n(%); n=15201	P-value
Demographic			
Age less than 60 years	3860 (8.6%)	1407 (9.3%)	0.02
Octagenarians	7245 (16.2%)	2554 (16.8%)	0.09
Nonagenarians	379 (0.9%)	176 (1.7%)	<0.001
Female	26907 (60.2%)	9385 (61.7%)	<0.001
Non-white ethnicity	12479 (82.1%)	38463 (86.0%)	<0.001
Non-elective admission	12979 (85.5%)	42425 (95.0%)	<0.001
Comorbidities			
Obesity	8953 (20.0%)	3011 (19.8%)	0.56
Tobacco Use Disorder	7685 (17.2%)	1959 (12.9%)	<0.001
Diabetes without complication	6461 (14.5%)	2196 (14.4%)	0.99
Diabetes with complication	82 (0.2%)	36 (0.2%)	0.20
Liver cirrhosis	193 (0.4%)	114 (0.8%)	<0.001
Parkinson's	495 (1.1%)	195 (1.3%)	0.80
CKD	3488 (7.8%)	1281 (8.4%)	0.01
Dialysis	67 (0.2%)	33 (0.2%)	0.08
Organ transplant	117 (0.3%)	39 (0.3%)	0.92
SLE	199 (0.4%)	69 (0.5%)	0.88
Ulcerative colitis	98 (0.2%)	28 (0.2%)	0.42
Sickle cell disease	23 (0.1%)	14 (0.1%)	0.08
Surgical Complications			
Wound dehiscence	14 (0.03%)	*** (0.03%)	0.92
Superficial SSI	*** (0.004%)	*** (0.02%)	0.08
PJI	183 (0.4%)	162 (1.1%)	<0.001
Periprosthetic mechanical complication	524 (1.2%)	228 (1.5%)	0.002
Periprosthetic dislocation	727 (1.6%)	273 (1.8%)	0.16
Periprosthetic fracture	84 (0.2%)	49 (0.3%)	0.002
Medical Complications			
DVT	15 (0.03%)	33 (0.2%)	<0.001

Table 2. Continued

PE	39 (0.1%)	36 (0.2%)	<0.001
Blood transfusion	573 (1.3%)	604 (4.0%)	<0.001
Blood loss anemia	3903 (8.7%)	2233 (14.7%)	<0.001
Pneumonia	95 (0.2%)	132 (0.9%)	<0.001
Myocardial infarction	10 (0.02%)	19 (0.1%)	<0.001
Acute renal failure	672 (1.5%)	662 (4.4%)	<0.001
Mortality	13 (0.03%)	26 (0.2%)	<0.001

CKD, Chronic kidney disease. SLE, Systemic Lupus Erythematosus. SSI, Surgical site infection. PJI, Periprosthetic joint infection. DVT, Deep Vein Thrombosis. PE, Pulmonary Embolism. P ≤ 0.05 statistically significant (in bold). ***Health Care Utility Project (HCUP) data use agreement precludes publishing of values between 1 to 10

Table 3. Multivariate analysis of independent predictors of higher costs following RTSA

	OR	95% CI Lower	95% CI Upper	P-value
Demographics				
Age less than 60 years	1.06	0.98	1.13	0.11
Nonagenarians	1.03	0.85	1.24	0.76
Female	0.99	0.95	1.03	0.54
Non-white ethnicity	1.31	1.25	1.38	<0.001
Non-elective admission	3.13	2.94	3.33	<0.001
Comorbidities				
Tobacco Use Disorder	0.75	0.72	0.80	<0.001
Liver cirrhosis	1.56	1.22	1.98	<0.001
CKD	1.06	0.99	1.13	0.12
Surgical Complications				
Periprosthetic infection	2.43	1.96	3.02	<0.001
Periprosthetic mechanical complication	1.28	1.09	1.50	0.002
Periprosthetic fracture	1.56	1.09	2.23	0.02
Medical Complications				
DVT	4.88	2.60	9.16	<0.001
PE	1.78	1.10	2.89	0.02
Blood transfusion	2.20	1.94	2.48	<0.001
Blood loss anemia	3.06	2.32	4.03	<0.001
Pneumonia	1.52	1.43	1.61	<0.001
Myocardial infarction	3.97	1.80	8.79	<0.001
Acute renal failure	2.28	2.03	2.55	<0.001
Mortality	3.08	1.51	6.29	0.002

CKD, Chronic kidney disease. PJI, Periprosthetic joint infection. DVT, Deep Vein Thrombosis. PE, Pulmonary Embolism.
P ≤ 0.05 statistically significant (in bold). ***Health Care Utility Project (HCUP) data use agreement precludes publishing of values between 1 to 10

Discussion

The rate of RTSA's being performed is rapidly rising each year, which demands further attention to its costs on hospital systems, especially with the growing implementation of bundled payments. While individual implant and staffing charges can be negotiated between payers and hospitals, charges associated with patients' post-operative inpatient stay can be mitigated with a better understanding of the drivers of higher costs following RTSA. In this study, we evaluate potential pre-operative and post-operative factors associated with higher inpatient costs following RTSA.

Non-elective admission was associated with higher overall costs, which is unsurprising as there is usually a longer length of stay for the treatment and diagnosis of unexpected medical issues. While significant on univariate analysis, sex and age were not associated with increased costs on multivariate analysis. Further analysis revealed a significant proportion of patients undergoing non-elective admission were female and over 90 years old. Displaced proximal humerus fractures are particularly common in elderly females with osteoporosis, for whom RTSA has become a popular surgical option.[14,15] This may account for the lack of associated higher costs for females and nonagenarians when controlling for confounding factors. Non-white patients undergoing RTSA were associated with higher costs, compared to white patients. There is well-established evidence supporting racial disparities among shoulder arthroplasties where minority ethnicity groups tend to have lower utilization rates, higher costs, longer length of stay, and higher readmission rates than white patients.[16-20]

Patients with cirrhosis were at increased odds of higher costs following RTSA. The impairment of the coagulation cascade in cirrhotic livers often leads to post-operative anemia and blood transfusions, which we found associated with higher costs. Similarly, patients with cirrhosis undergoing total hip arthroplasty and total knee arthroplasty are associated with higher hospital costs, complications, and length of stay in matched studies.[21-23] Rosas et al[24] stratified absolute reimbursement costs following ATSA by comorbidity and found cirrhosis had the third greatest 90-day fees, after hepatitis C and atrial fibrillation. The other comorbidities we studied had lesser reimbursement fees in their study for ATSA, which include obesity, morbid obesity, smoking history, diabetes, and CKD. Hepatitis C is the most common cause of cirrhosis in the United States and is widely undiagnosed.[25] While we were unable to identify how many patients with cirrhosis in our study had hepatitis C, hepatitis C has shown to have an increased risk for multiple post-operative surgical and medical complications, including blood transfusions following ATSA.[26]

In a study on ATSA between 1993 and 2010, Davis et al[3] found multiple medical comorbidities including diabetes, CKD, chronic obstructive pulmonary disease (COPD), coronary artery disease (CAD), and congestive heart failure (CHF), associated with increased total hospital charges. We did not find diabetes or CKD independently associated with higher costs following RTSA. This could be attributed to the evolution of pre-operative evaluation and optimization practices over the past three decades, where there is more awareness and effort to prevent diabetes and CKD-related complications.[27-29] Our findings though are consistent with those of Ponce et al[11] who studied diabetics undergoing ATSA. While they found a higher risk of perioperative morbidity and mortality, diabetes was not associated with increased inpatient costs following ATSA. Surprisingly, we found patients with tobacco use disorder were associated with normal overall inpatient costs. While current tobacco use is associated with increased wound complications and surgical site infections following shoulder arthroplasty,[30] some studies have demonstrated no differences in outcomes between smokers and non-smokers following shoulder arthroplasty.[31-33] The ICD-10 diagnosis of tobacco use disorder in a patient's medical chart does not always imply the patient is a current tobacco user. Often surgeons will require patients to be tobacco-free for a period of time prior to elective surgery, as part of pre-operative optimization, so many of the patients in our cohort may be former smokers.

Of the surgical complications evaluated, those that typically require a return to the operating room were associated with higher costs. These included PJI, periprosthetic mechanical complication, and periprosthetic fracture. Chalmers et al[10] found the operative costs alone can account for up to 70% of the total costs following shoulder arthroplasty, of which 82% were supply use costs. This can vary depending on the implants and tools required in a revision for an infection or fracture, but it is an undoubtedly sizable expense. PJI had the highest odds of increased cost, with an odds ratio of 2.43, compared to fracture which had an odds ratio of 1.56. O Connor et al[34] found the higher overall costs from orthopedic infections were largely driven by longer hospital stay, which was affected by the length of inpatient antibiotic therapy. As the rate of shoulder arthroplasties rises each year, the rate of PJI's will proportionally as well, which is a major economic concern. Schick et al[35] found the average total hospital charge per PJI to be $130,290 in 2021 based on cost adjustment using the NIS database. Between 2011 and 2018, the annual charges for PJI increased by more than 300%, with a 10-fold growth in charges for RTSA specifically.[35] Meanwhile, periprosthetic dislocation, wound dehiscence, and superficial SSI were not associated with higher costs. These all have the potential to be managed non-operatively with closed reduction, wound care, and antibiotics, respectively, depending on the severity of each. Nonetheless, it is imperative to continue to identify strategies to prevent PJI's to alleviate the economic burden that shoulder PJI's place on the healthcare system.

The post-operative medical complications evaluated generally had higher odds of high costs than those of surgical complications [Table 3]. While surgical-related costs are high, the cost of medical complications requiring extended length of stay, medical workup, and consultations can be higher. This is supported by Davis et al's [3] study on hospital charges following ATSA, which found surgical complications significantly increased overall charges by about 18-23% while complications related to medical care increased overall charges by 60%. We found DVT, myocardial infarction, mortality, acute renal failure, blood loss anemia, and blood transfusion to be the strongest predictors of higher costs following surgery, which is consistent with previous studies.[36,37] Each of these disease processes require a combination of laboratory tests, imaging, and interventions, along with additional days in the hospital. Unsurprisingly, a strong correlation exists for both investigative tests and longer hospital length of stay with higher total inpatient costs following arthroplasty.[4,38] It is worth noting though that blood transfusion and mortality are surrogates of other disease processes associated with increased cost. Pre-operative optimization and proactive preventative care measures are imperative to help mitigate these postoperative complications and their associated expenditures from occurring.[39]

There are a few limitations of this study, primarily the use of a national patient registry to collect data. The data is dependent on accurate documentation and coding by medical providers, therefore, there may be some underreporting of comorbidities and post-operative complications. Secondly, among different hospitals across the United States, there is variability in inpatient costs for similar services due to the heterogeneity of insurance plan types and hospital billing structures.[40] While patients were assigned to high cost and normal cost groups based on cost percentile, these groups may have some bias related to factors specific to individual hospitals' financial systems, independent of clinical factors. Additionally, bundled payments address all charges related to a surgery, which include outpatient follow-up visits for a period from anywhere up to 30 to 90 days following surgery. The database only includes information related to the surgery's inpatient admission but evaluating outpatient follow-up visits is beyond the scope of this study. Finally, we are unable to specify the charges related to any medical readmissions or charges associated with revision surgery during another admission. The strengths of this study, however, include a cohort size large enough to generate a decent sample size to evaluate rare complications, such as periprosthetic complications which occurred less than two percent of the time in our study. Another strength is the generalizability of our study. It is established there is wide variation in charges following shoulder arthroplasty between different institutions.[3,6,13] Our cohort represents a nationwide representation of patients and payer groups, which minimizes variations in costs among institutions.

Conclusion

Understanding the economic impact of RTSA is important for providers and healthcare systems. Patients with cirrhosis and those who undergo non-elective admission are at increased odds of higher inpatient costs following RTSA. Post-operative surgical complications that often require a return to the operating room, especially periprosthetic infection, are associated with higher inpatient costs. However, postoperative medical complications, including DVT and myocardial infarction, are the most substantial factors associated with increased costs following RTSA. Pre-operative optimization and preventative care measures to prevent infection and medical complications are imperative to mitigate the economic burden of RTSA's.

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Authors Contribution:
Dang-Huy Do MD: Conceptualization, validation, writing original draft, writing review and editing, visualization, project administration.
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Declaration of Informed Consent: There is no information (names, initials, hospital identification numbers, or photographs) in the submitted manuscript that can be used to identify patients, as all information obtained from the national database were already de-identified.

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References

1. Best MJ, Aziz KT, Wilckens JH, McFarland EG, Srikumaran U. Increasing incidence of primary reverse and anatomic total shoulder arthroplasty in the United States. J Shoulder Elbow Surg. 2021; 30(5):1159-1166. doi:10.1016/j.jse.2020.08.010.
2. Wagner ER, Farley KX, Higgins I, Wilson JM, Daly CA, Gottschalk MB. The incidence of shoulder arthroplasty: rise and future projections compared with hip and knee arthroplasty. J Shoulder Elbow Surg. 2020; 29(12):2601-2609. doi:10.1016/j.jse.2020.03.049.
3. Davis DE, Paxton ES, Maltenfort M, Abboud J. Factors affecting hospital charges after total shoulder arthroplasty: an evaluation of the National Inpatient Sample database. J Shoulder Elbow Surg. 2014; 23(12):1860-1866. doi:10.1016/j.jse.2014.04.002.
4. 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; 100(23):2050-2056. doi:10.2106/JBJS.18.00281.
5. Chawla SS, Whitson AJ, Schiffman CJ, Matsen III FA, Hsu JE. Drivers of lower inpatient hospital costs and greater improvements in health-related quality of life for patients undergoing total shoulder and ream-and-run arthroplasty. J Shoulder Elbow Surg. 2021; 30(8):e503-e516. doi:10.1016/j.jse.2020.10.030.
6. Carducci MP, Mahendraraj KA, Menendez ME, et al. Identifying surgeon and institutional drivers of cost in total shoulder arthroplasty: a multicenter study. J Shoulder Elbow Surg. 2021;

30(1):113-119. doi:10.1016/j.jse.2020.04.033.
7. Steen BM, Cabezas AF, Santoni BG, et al. Outcome and value of reverse shoulder arthroplasty for treatment of glenohumeral osteoarthritis: a matched cohort. J Shoulder Elbow Surg. 2015; 24(9):1433-41. doi:10.1016/j.jse.2015.01.005.
8. Kennon JC, Songy CE, Marigi E, et al. Cost analysis and complication profile of primary shoulder arthroplasty at a high-volume institution. J Shoulder Elbow Surg. 2020; 29(7):1337-1345. doi:10.1016/j.jse.2019.12.008.
9. Bhat SB, Liss FE, Beredjiklian PK. Economic Analysis of the Cost of Implants Used for Treatment of Distal Radius Fractures. Arch Bone Jt Surg. 2018; 6(5):371-375.
13. Gowd AK, Agarwalla A, Beck EC, et al. Prediction of total healthcare cost following total shoulder arthroplasty utilizing machine learning. J Shoulder Elbow Surg. 2022; 31(12):2449-2456. doi:10.1016/j.jse.2022.07.013.
14. Maugendre E, Gadisseux B, Chantelot C, et al. Epidemiology and mortality in older patients treated by reverse shoulder arthroplasty for displaced proximal humerus fractures. Orthop Traumatol Surg Res. 2019; 105(8):1509-1513. doi:10.1016/j.otsr.2019.07.026.
15. Osterhoff G, O'Hara NN, D'Cruz J, et al. A Cost-Effectiveness Analysis of Reverse Total Shoulder Arthroplasty versus Hemiarthroplasty for the Management of Complex Proximal Humeral Fractures in the Elderly. Value Health. 2017; 20(3):404-411. doi:10.1016/j.jval.2016.10.017.
16. Farley KX, Dawes AM, Wilson JM, et al. Racial Disparities in the Utilization of Shoulder Arthroplasty in the United States: Trends from 2011 to 2017. JB JS Open Access. 2022; 7(2) doi:10.2106/JBJS.OA.21.00144.
17. Markes AR, Pareek A, Mesfin A, Benjamin Ma C, Ward D. Racial and Gender Shoulder Arthroplasty Utilization Disparities of High- and Low-Volume Centers in New York State. J Shoulder Elb Arthroplast. 2021; 5:24715492211041901. doi:10.1177/24715492211041901.
18. Ling K, Leatherwood W, Fassler R, Burgan J, Komatsu DE, Wang ED. Disparities in postoperative total shoulder arthroplasty outcomes between Black and White patients. JSES Int. 2023; 7(5):842-847. doi:10.1016/j.jseint.2023.05.009.
19. Singh JA, Ramachandran R. Persisting Racial Disparities in Total Shoulder Arthroplasty Utilization and Outcomes. J Racial Ethn Health Disparities. 2016; 3(2):259-66. doi:10.1007/s40615-015-0138-3.
20. Best MJ, Aziz KT, McFarland EG, Martin SD, Rue JH, Srikumaran U. Worsening racial disparities in patients undergoing anatomic and reverse total shoulder arthroplasty in the United States. J Shoulder Elbow Surg. 2021; 30(8):1844-1850. doi:10.1016/j.jse.2020.10.023.
21. Cheppalli NS, Metikala S, Beale J, Mounsamy V, Sambandam S. Total Hip Arthroplasty in Cirrhosis is Associated with Increased Complications during the Hospital Stay, Length of Stay, and Cost of Care: A Propensity Matched Database Study. Arch Bone Jt Surg. 2023; 11(5):330-336. doi:10.22038/ABJS.2023.68339.3234.
22. Metikala S, Venishetty N, Cheppalli N, Jones H, Mounsamy V, Sambandam S. Patients With Cirrhosis Have Higher Costs of Care, Longer Length of Stays, and More Perioperative Complications Following Total Knee Arthroplasty: A National Inpatient Sample-Based Study. Cureus. 2023; 15(10):e47317. doi:10.7759/cureus.47317.
23. Parikh ND, Chang YH, Tapper EB, Mathur AK. Outcomes of Patients with Cirrhosis Undergoing Orthopedic Procedures: An Analysis of the Nationwide Inpatient Sample. J Clin Gastroenterol. 2019; 53(9):e356-e361. doi:10.1097/MCG.0000000000001091.
24. Rosas S, Sabeh KG, Buller LT, Law TY, Kalandiak SP, Levy JC. Comorbidity effects on shoulder arthroplasty costs analysis of a nationwide private payer insurance data set. J Shoulder Elbow Surg. 2017; 26(7):e216-e221. doi:10.1016/j.jse.2016.11.044.
25. Scaglione S, Kliethermes S, Cao G, et al. The Epidemiology of Cirrhosis in the United States: A Population-based Study. J Clin Gastroenterol. 2015; 49(8):690-6. doi:10.1097/MCG.0000000000000208.
26. Cancienne JM, Dempsey IJ, Holzgrefe RE, Brockmeier SF, Werner BC. Is Hepatitis C Infection Associated With a Higher Risk of
10. Chalmers PN, Kahn T, Broschinsky K, et al. An analysis of costs associated with shoulder arthroplasty. J Shoulder Elbow Surg. 2019; 28(7):1334-1340. doi:10.1016/j.jse.2018.11.065.
11. Ponce BA, Menendez ME, Oladeji LO, Soldado F. Diabetes as a risk factor for poorer early postoperative outcomes after shoulder arthroplasty. J Shoulder Elbow Surg. 2014; 23(5):671-8. doi:10.1016/j.jse.2014.01.046.
12. Chawla SS, Schiffman CJ, Whitson AJ, Matsen III FA, Hsu JE. Drivers of inpatient hospitalization costs, joint-specific patient-reported outcomes, and health-related quality of life in shoulder arthroplasty for cuff tear arthropathy. J Shoulder Elbow Surg. 2022; 31(12):e586-e592. doi:10.1016/j.jse.2022.05.018.
Complications After Total Shoulder Arthroplasty? Clin Orthop Relat Res. 2016; 474(12):2664-2669. doi:10.1007/s11999-016-4979-9.
27. Older P, Hall A, Hader R. Cardiopulmonary exercise testing as a screening test for perioperative management of major surgery in the elderly. Chest. 1999; 116(2):355-62. doi:10.1378/chest.116.2.355.
28. Grocott MP, Mythen MG. Perioperative Medicine: The Value Proposition for Anesthesia? A UK Perspective on Delivering Value from Anesthesiology. Anesthesiol Clin. 2015; 33(4):617-28. doi:10.1016/j.anclin.2015.07.003.
29. Levy N, Grocott MPW, Carli F. Patient optimisation before surgery: a clear and present challenge in peri-operative care. Anaesthesia. 2019; 74 Suppl 1:3-6. doi:10.1111/anae.14502.
30. Althoff AD, Reeves RA, Traven SA, Wilson JM, Woolf SK, Slone HS. Smoking is associated with increased surgical complications following total shoulder arthroplasty: an analysis of 14,465 patients. J Shoulder Elbow Surg. 2020; 29(3):491-496. doi:10.1016/j.jse.2019.07.012.
31. Walters JD, George LW, 2nd, Walsh RN, et al. The effect of current and former tobacco use on outcomes after primary reverse total shoulder arthroplasty. J Shoulder Elbow Surg. 2020; 29(2):244-251. doi:10.1016/j.jse.2019.05.045.
32. Morris BJ, O'Connor DP, Torres D, Elkousy HA, Gartsman GM, Edwards TB. Risk factors for periprosthetic infection after reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2015; 24(2):161-6. doi:10.1016/j.jse.2014.05.020.
33. Wells DB, Holt AM, Smith RA, Brolin TJ, Azar FM, Throckmorton TW. Tobacco use predicts a more difficult episode of care after anatomic total shoulder arthroplasty. J Shoulder Elbow Surg. 2018; 27(1):23-28. doi:10.1016/j.jse.2017.06.033.
34. O'Connor O, Thahir A, Krkovic M. How Much Does an Infected Fracture Cost? Arch Bone Jt Surg. 2022; 10(2):135-140. doi:10.22038/abjs.2021.53590.2665.
35. Schick S, Elphingstone J, Murali S, et al. The incidence of shoulder arthroplasty infection presents a substantial economic burden in the United States: a predictive model. JSES Int. 2023; 7(4):636-641. doi:10.1016/j.jseint.2023.03.013.
36. Stokes SM, Scaife CL, Brooke BS, et al. Hospital Costs Following Surgical Complications: A Value-driven Outcomes Analysis of Cost Savings Due to Complication Prevention. Ann Surg. 2022; 275(2):e375-e381. doi:10.1097/SLA.0000000000004243.
37. Healy MA, Mullard AJ, Campbell DA, Jr., Dimick JB. Hospital and Payer Costs Associated With Surgical Complications. JAMA Surg. 2016; 151(9):823-30. doi:10.1001/jamasurg.2016.0773.
38. Cheng E, Lewin A, Churches T, Harris IA, Naylor J. Cost of investigations during the acute hospital stay following total hip or knee arthroplasty, by complication status. BMC Health Serv Res. 2020; 20(1):1036. doi:10.1186/s12913-020-05892-1.
39. Musich S, Wang S, Hawkins K, Klemes A. The Impact of Personalized Preventive Care on Health Care Quality, Utilization, and Expenditures. Popul Health Manag. 2016; 19(6):389-397. doi:10.1089/pop.2015.0171.
40. Shen C, Moss JL. Large variations in hospital pricing for standard procedures revealed. BMC Res Notes. 2022; 15(1):129. doi:10.1186/s13104-022-06014-2.

Appendix

Appendix. ICD Codes used

RTSA ICD codes	Obese Codes	Comorbidities codes	Surgical Complications codes	Medical Complications codes
0RRK00Z 0RRJ00Z	E660 E6601 E6609 E661 E662 E668 E669 Z6830 Z6831 Z6832 Z6833 Z6834 Z6835 Z6836 Z6837 Z6838 Z6839	Diabetes without complications E119	Periprosthetic fracture T84010A, T84011A, T84012A, T84013A, T84018A, T84019A, M9665, M96661, M96662, M96669, M96671, M96672, M96679, M9669, M9701XA, M9702XA, M9711XA, M9712XA	Acute renal failure N170, N171, N172, N178, N179
		Diabetes with complications E1169		Myocardial infarction I2101, I2102, I2111, I2113, I12114, I12119, I2121, I12129, I21A1
		Tobacco related disorder Z87891		Blood loss anemia D62
			Periprosthetic dislocation T84020A, T84021A, T84022A, T84023A, T84028A, T84029A	Pneumonia J189, J159, J22
				Blood transfusion 30233N1
			Periprosthetic mechanical complications T84090A, T84091A, T84092A, T84093A, T84098A, T84099A	Pulmonary embolism I2602, I2609, I2692, I2699
			Periprosthetic joint infection T8450XA, T8451XA, T8452XA, T8453XA, T8454XA, T8459XA	Deep venous thrombosis I82401, I82402, I82403, I82409, I82411, I82412, I82413, I82419, I82421, I82422, I82423, I82429, I82431, I82432, I82433, I82439, I82441, I82442, I82443, I82449, I82491, I82492, I82493, I82499, I824Y1, I824Y2, I824Y3, I824Y9, I824Z1, I824Z2, I824Z3, I824Z4
			Superficial surgical site infection T8141XA	
			Wound dehiscence T8130XA, T8131XA, T8132XA	