A novel comorbidity risk score for predicting postoperative 30-day complications in total shoulder arthroplasty and elucidation of potential racial disparities

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Background: Efficient and effective preoperative identification of those patients with elevated risk may allow for more cost-effective interventions, accurate bundled payment adjustments, and overall improved patient care. Few comorbidity indices have provided clinical utility and adequate discriminative ability in the setting of complications after shoulder arthroplasty (SA).

Methods: The American College of Surgeons National Surgical Quality Improvement Program database was queried for anatomic and/or reverse SA procedures between 2010 and 2019. A subset of comorbidities were utilized including end-stage renal disease, history of hypertension, chronic obstructive pulmonary disease, functional status, history of bleeding disorder, and disseminated cancer.

Results: A total of 25,927 patients with an average age of 69.2 (standard deviation ±9.5) years were included in the study. Patients with a comorbidity risk score (CRS) at or above 2 were indicated to have at least a 29.6% 30-day postoperative complication rate after undergoing total shoulder arthroplasty, significantly higher than the described average of approximately 15%. The area under receiver operator curve for the novel CRS scoring system was 0.595, indicating fair discriminative ability to predict 30-day postoperative complications after SA. This illustrates a discriminative ability similar to that of the American Society of Anesthesiologists classification (0.584, confidence interval [CI] 0.578-0.589), modified Charlson Comorbidity Index (0.567, CI 0.561-0.573), and modified Frailty Index (0.534, CI 0.529-0.539), each of which are common comorbidity indices used for the National Surgical Quality Improvement Program database. The average CRS for the population was 0.8537 (CI 0.8011-0.8150; \( P < .05 \)) while that for the Black demographic was 1.08 (CI 1.03-1.13; \( P < .001 \)). Our results suggest that if the disparity in CRS among races was corrected, the average complication rate would be decreased by 2.0%.

Discussion and Conclusion: A higher CRS score resulted in higher rates of 30-day postoperative complications following SA. Black patients had a higher average CRS than all other races illustrating a racial disparity in comorbidity risk. Although the average complication rate of each race would still be unequal, this could mitigate some of the racial disparities observed and decrease the overall 30-day complication rate in SA. With the rise of bundled payments further increasing the need to preoperatively identify patients at high risk for costly complications, the CRS is based on easily identified, relevant comorbidities that may be an advantageous tool to identify patients at increased risk of complications following SA.

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following SA in the year of 2025. Some of the most common complications following SA include instability, loosening, infection, notching, nerve injury, and fractures. Many of which may require reoperation. Although some adverse outcomes are inherent to surgery, many can be mitigated by early identification of those who may be at increased risk of postoperative complications. Efficient and effective preoperative identification of those patients with elevated risk may allow for more cost-effective interventions, accurate bundled payment adjustments, and overall improved patient care.

To that end, a number of comorbidity scores exist in the current literature that attempt to provide prognostic utility related to complications after a major surgery. For SA specifically, the American Society of Anesthesiologists (ASA), modified Charlson Comorbidity Index (mCCI), and modified Frailty Index (mFI) are index scores commonly used in national data sets to evaluate patients’ risk of adverse outcomes. However, the discriminative ability and clinical utility of these indices have been limited due to inherent subjectivity and/or not being sensitive enough to adequately capture low comorbidity burden common in elective orthopedic surgery patients populations, commonly resulting in the overwhelming majority of patients having a comorbidity score of 0. In addition to the overall rates of SA and associated complications, a growing number of studies continue to highlight racial disparities in orthopedic care including shoulder, hip, and ankle arthroplasties. However, a limited number of studies have adequately assessed the relationship between race and a comorbidity index with significant discriminative ability for those at elevated risk of surgical complications. With a growing utilization of bundled payments and increasing awareness of racial disparities in health care, early identification of potentially costly complications is of paramount importance to allow for any potential preemptive interventions that may allow improved outcomes. Given the possible implications of an inappropriately adjusted bundled payment, such as potentially furthering already existing disparities due to misaligned incentives, it is a necessity to thoroughly investigate and describe these existing disparities to better guide clinicians in patient education and for optimization of outcomes for all segments of the population.

The primary aim of this study is to identify an at-risk population (utilizing a novel comorbidity risk score [CRS]) that may require additional care beyond typical postoperative management in SA. The secondary aim of the current study is to evaluate potential racial disparities in the use of this tool as they pertain to SA. Our hypothesis is that a higher CRS score will increase the likelihood of postoperative complications. We also hypothesize that a racial disparity will persist and be exhibited with Black patients having a higher CRS than other races.

**Data source**

This investigation utilized data from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database from the years of 2010–2019. NSQIP is a national prospective database that collects over 150 verified variables including demographics, comorbidities, preoperative risk factors, intraoperative variables, and 30-day postoperative mortality and morbidity outcomes for patients undergoing major inpatient and outpatient surgical procedures. The NSQIP database maintains strict data quality standards, and medical centers employ trained surgical clinical reviewers who submit data. There also must be at least an 80% 30-day follow-up rate and an interrater reliability of greater than 95% for a medical center to be included in the final NSQIP database.

**Inclusion and exclusion criteria**

Total SA (TSA) and reverse total SA (RSA) cases in the NSQIP database between 2010 and 2019 were included. The Current Procedural Terminology (CPT) code 23472 (“total arthroplasty of glenohumeral joint”) was used to select patients who underwent anatomic TSA or RSA. The patient inclusion criteria consisted of patients having a complete data set including race, gender, age, preoperative comorbidities, hospital length of stay (LOS), discharge status, and postoperative complications. Patients were excluded if they had the following preoperative diagnosis listed for additional conditions: fracture, sepsis, infection, prosthesis complications, orthopedic after care, and emergent surgery. Patients with the following CPT codes listed for additional procedures were also excluded: revision SA (23473, 23474); hemiarthroplasty (23470); removal of prosthesis (23334); or removal of implant (20680).

**Data of interest**

Data of interest included patient demography (age, body mass index, sex, race, etc.), comorbidities (diabetes, smoking status, etc.), perioperative course (operative time, postoperative LOS, etc.), surgical complications (site infections, wound dehiscence, etc.), and postoperative course (return to operating room, 30-day readmission, etc.). Commonly collected proxies that have been described in the literature to be, in variable degrees, related to social support include end-stage renal disease, history of hypertension, chronic obstructive pulmonary disease (COPD), functional status, bleeding disorder, and disseminated cancer. These values were collected and assessed as influential comorbidities. Information on these factors was available in the NSQIP database and is often readily available in a patient’s electronic health record. As such, we specifically chose factors that are clinically relevant that they would be available for any existing patient in a surgeon’s practice without additional data collection.

**Statistical analysis**

A mCCI was calculated from the available NSQIP data. Points were assigned to patients based on their preoperative comorbidities, including age, cancer, COPD, congestive heart failure, ascites, end-stage renal disease, diabetes mellitus type 1, and diabetes mellitus type 2. Descriptive statistics were calculated using Chi-squared tests and one-way analysis of variance where appropriate. For initial assessment of the comorbidities to be assessed, univariate logistic regressions were used. Factors that were significant under this analysis were included in a multivariable binary logistic regression analysis modeling the odds of any complication based on comorbidity factors. Any complication was defined as wound, cardiac, respiratory, renal, neurological, or septic/systemic complications in addition to deep vein thrombosis/pulmonary embolism, postoperative blood transfusion, urinary tract infection, extended LOS (3+ days), or reoperation.

**Calculation of the CRS**

The independent comorbidities included end-stage renal disease, history of hypertension, COPD, functional status, bleeding disorder, and disseminated cancer. Each respective nonexponentiated coefficient from the multivariable model using these markers was used to calculate an integer risk score based on a...
simple calculation (coefficients/smallest coefficient). Model performance was assessed using the receiver operator characteristic analysis, specifically with the area under receiver operator curve (AUROC). Finally, complication rate by CRS was calculated for the cohort in this study. A cutoff of N ≥ 50 patients was used to determine which score values the complication rate was reported for; for scores under this N, an additional complication in 1 patient would change the estimated complication rate by more than 2%. A threshold of $P < .05$ was used to determine statistical significance. SPSS V27.0 was used (IBM Corporation, Armonk, NY, USA).

**Results**

Of the 29,243 surgical cases identified, a total of 29,927, or 88.67%, patients satisfied the criteria for analysis (Fig. 1). Patient exclusion criteria consisted of concurrent procedure exclusions including revision TSA/RSA (18 cases), hemiarthroplasty (17 cases), removal of prosthesis (36 cases), or removal of implant (377 cases) and diagnosis exclusions including fracture (1874 cases), sepsis (2 cases), infection (25 cases), prosthesis complication (588 cases), orthopedic aftercare (53 cases), and emergent surgery (304 cases). The average age was 69.2 (±9.5) years, and 46.2% of the cohort was composed of male and 53.8% of female patients.

Of these patients, 21,013 (81.05%) were White, 1215 (4.69%) were Black, 955 (3.68%) were Hispanic, 199 (0.76%) were Asian/Pacific Islander, and 2441 (9.41%) were of unknown/other race. The mean CRS by patient race varied significantly among different racial/ethnic groups in terms of age ($P < .001$), mCCI ($P < .001$), ASA class ($P < .001$), preoperative functional status ($P = .005$), cigarette smoking ($P < .001$), steroid use ($P < .001$), bleeding disorders ($P = .002$), preoperative transfusions ($P = .007$), and hypertension requiring medical therapy ($P < .001$). The most common complications throughout the cohort included blood transfusion, readmission, and reoperation. There was also a significant difference between patients of different racial/ethnic groups in wound complications ($P < .001$), hospital readmission ($P < .001$), all complications combined except extended LOS ($P = .027$), and LOS of 3 or more days ($P < .001$; Table II).

Our final CRS model (Table III) contained 6 independent comorbidities, all of which were significant predictors of complications from our data set: end-stage renal disease ($P < .001$), hypertension on medical therapy ($P < .001$), COPD ($P < .001$), nonindependent functional status ($P < .001$), bleeding disorder ($P < .001$), and disseminated cancer ($P < .001$). The integer scores for these predictors ranged from 1 to 6, with a maximum total score of 21. This model was defined as the CRS. The AUROC (a measure of discriminative ability) for this model was 0.595, which indicates that there is a 59.5% chance of correctly predicting whether a given patient will have a complication using our model.

The AUROC for our novel CRS scoring system (0.595) indicates a fair discriminative ability to predict 30-day postoperative complications after SA (Fig. 2). This illustrates a similar discriminative ability compared to that of the ASA classification (0.604) and the modified CCI (0.597) as they were calculated in our data set. Other studies have also found similar AUROC values for ASA classification (0.584, 95% CI 0.578-0.589), mCCI (0.567, 95% CI 0.561-0.573), and mFI (0.534, 95% CI 0.529-0.539). In this data set, the mean complication rate was 18.6%. In our data set, there was a stepwise increase in complication rate with increasing CRS (Table IV). Patients with a CRS of 2 had a complication rate of 29.6%, and 9.1% of the study population had a CRS of 2 or higher. Patients with a CRS of 0 had a complication rate of 12.3%.

**Figure 1** Patient selection. TSA, total shoulder arthroplasty; RSA, reverse shoulder arthroplasty.

**Discussion**

Current comorbidity indices have had a limited utility and ability to identify those most at risk of complications following SA. Our aim in this study was to develop a straightforward and effective tool capable of identifying those most at risk of postoperative complications after SA. The CRS described here is a tool which may be used to achieve this aim utilizing clinically relevant and readily available data points. The AUROC for our novel CRS scoring system was 0.676, indicating a fair discriminative ability to predict 30-day postoperative complications after SA. This demonstrates a similar discriminative ability to the most common comorbidity indices currently utilized, including ASA, mCCI, and mFI.

Our novel CRS provides improved clinical utility relative to the aforementioned indices due to its straightforward scoring system, comparable discriminative ability, and easily identified variables. The ASA is a scale that relies on a physician’s gestalt to describe a patient’s physical status before surgery. mCCI is a tabulated comorbidity index (that uses a subset of variables from the original Charlson Comorbidity Index) developed to predict 1-year all-cause mortality. Finally, mFI is a newer modified tabulated index (that...
uses a subset of variables from the original Frailty Index) created to identify the decrease in physiologic reserves and multisystem impairments separate from chronologic age. The use of mCCI and mFI is antiquated as most modern, national data sets do not collect the extensive variables required to calculate the CCI and FI. Yi et al analyzed these indices in patients undergoing SA in the NSQIP database and found only mCCI and mFI to be associated with adverse events and each of these to only have a moderate ability to predict complications. Thus, comparatively, the CRS provides a more easily applied, practical, and effective tool to identify those at increased risk of complications in the 30-day period following SA. With the increasing awareness of bundled payments, it is

Table I

Descriptive statistics.

| Variable | Race | P value |
|----------|------|---------|
| N        | White | Black  | Hispanic | Asian/Pacific Islander | Native American | Unknown/other |
| Age (mean, 95% CI) | 210 | 1215 | 955 | 199 | 104 | 2441 |
| CCI (mean, 95% CI) | 2.79 (2.78-2.81) | 2.57 (2.49-2.64) | 2.81 (2.73-2.89) | 2.82 (2.66-2.99) | 2.27 (2.05-2.49) | 2.74 (2.70-2.79) |
| ASA (mean, 95% CI) | 2.56 (2.56-2.57) | 2.71 (2.67-2.74) | 2.54 (2.50-2.58) | 2.48 (2.40-2.56) | 2.61 (2.50-2.71) | 2.45 (2.43-2.48) |
| Functional status (% independent) | 98.1 | 97.3 | 96.7 | 96.4 | 98.1 | 98.5 |
| Smoker (%) | 9.3 | 20.7 | 9.2 | 8.0 | 15.4 | 10.7 |
| Steroid use (%) | 4.8 | 5.9 | 6.3 | 10.1 | 9.6 | 4.3 |
| Bleeding disorder (%) | 2.5 | 2.3 | 2.6 | 1.0 | 1.9 | 1.2 |
| Preop transfusion (%) | 0.1 | 0.3 | 0.2 | 0 | 0 | 0.0 |
| Weight loss >10% in past 6 mo (%) | 0.2 | 0.4 | 0.2 | 0.5 | 0 | 0.1 |
| Hypertension requiring medication (%) | 67.3 | 79.2 | 67.7 | 71.4 | 61.5 | 57.6 |
| BUN (mean, 95% CI) | 18.9 (18.8-19.1) | 17.1 (16.6-17.6) | 17.9 (17.4-18.5) | 18.6 (17.5-19.8) | 15.9 (14.7-17.1) | 18.2 (17.9-18.6) |
| Creatinine (mean, 95% CI) | .95 (.94-.95) | 1.14 (1.08-1.21) | .93 (.89-.97) | .97 (.89-1.05) | .86 (.81-.91) | .92 (.90-.94) |

CI, confidence interval; CCI, Charlson Comorbidity Index; ASA, American Society of Anesthesiologists; BUN, blood urea nitrogen. Bold indicates statistical significance (P < .05).

Table II

Patient outcomes and complications.

| Variable | Race | P value |
|----------|------|---------|
| Operative time (mean, 95% CI) | 106 (106-107) | 118 (115-121) | 112 (109-115) | 110 (104-116) | 119 (109-128) | 115 (113-116) |
| Wound complications (%) | 0.3 | 0.4 | 0.2 | 0 | 1.9 | 0.6 |
| Respiratory (%) | 0.5 | 0.7 | 0.8 | 0 | 0 | 0.7 |
| Cardiac (%) | 0.3 | 0.2 | 0.1 | 0.5 | 0 | 0.2 |
| Renal (%) | 0.1 | 0.1 | 0.2 | 0 | 0 | 0.1 |
| Neurologic (%) | 0.1 | 0.1 | 0 | 0 | 0 | 0.1 |
| Systemic (%) | 0.2 | 0.2 | 0.2 | 0 | 0 | 0.1 |
| DVT/PE (%) | 0.5 | 0.7 | 0.4 | 0 | 0 | 0.6 |
| UTI (%) | 0.7 | 0.4 | 0.6 | 0.5 | 0 | 0.7 |
| Blood transfusion (%) | 1.6 | 2.1 | 2.6 | 3.0 | 1.0 | 1.5 |
| Readmission (%) | 2.5 | 4.0 | 3.5 | 1.0 | 1.0 | 2.0 |
| Reoperation (%) | 1.0 | 1.3 | 1.4 | 1.0 | 1.9 | 0.9 |
| All complications (excluding extended LOS) (%) | 5.7 | 7.7 | 7.0 | 4.5 | 3.8 | 5.6 |

CI, confidence interval; LOS, length of stay; DVT/PE, deep vein thrombosis/pulmonary embolism; UTI, urinary tract infection. Bold indicates statistical significance (P < .05).

Table III

Development of CRS model.

| Marker of support | Odds ratio | 95% Confidence interval | P value | Coefficient Raw Score |
|-------------------|------------|-------------------------|---------|----------------------|
| End-stage renal disease | 3.896 | 2.456 | 6.181 | <.001 | 1.36 | 2.97 |
| COPD | 1.874 | 1.676 | 2.095 | <.001 | 0.63 | 1.37 |
| Hypertension treated with medication | 1.581 | 1.471 | 1.699 | <.001 | 0.46 | 1.00 |
| DVT/PE | 3.796 | 2.078 | 6.933 | <.001 | 1.33 | 2.92 |
| Nonindependent functional status | 4.686 | 3.909 | 5.618 | <.001 | 1.55 | 3.37 |
| Bleeding disorder | 1.992 | 1.673 | 2.371 | <.001 | 0.69 | 1.50 |
| Model performance | AUROC | 0.595 | 0.594 | 0.0-13 |
| CRS model | 0.597 | 0.594 | 3.00 |
| ASA classification | 0.694 | 0.594 | 3.00 |
| Modified CCI | 0.597 | 0.594 | 3.00 |

CRS, comorbidity risk score; AUROC, area under receiver operator curve; ASA, American Society of Anesthesiologists; COPD, chronic obstructive pulmonary disease; UTI, urinary tract infection; DVT/PE, deep vein thrombosis/pulmonary embolism; CCI, Charlson Comorbidity Index. The outcome variable was any wound, cardiac, respiratory, renal, neurologic, or septic complications, as well as DVT/PE, reoperation, readmission, blood transfusion, and UTI. Bold indicates statistical significance (P < .05).
advantageous to use a tool such as the CRS which can be easily calculated and documented by office administration without requiring physician time, input, and resources.

This study has also shed light on a potential disparity in the CRS between the various races. Black patients had a higher average CRS (1.08, CI 1.03-1.13, \( P < .001 \)) than all other races (Table IV). An important trend identified in our data set was that a lower CRS for each race generally resulted in a lower rate of complications (Table VI). Thus, regardless of race, a lower CRS results in lower complication risk. Our results suggest that if the average CRS for each race was equal to the overall average (0.8537, CI 0.8011-0.8150, \( P < .05 \)), then the average complication rate would decrease by approximately 2%. Although the average complication rate of each race would still be unequal, this could, ideally, mitigate some of the racial disparities observed and decrease the overall 30-day complication rate of SA. Our findings are consistent with previous studies that found various racial disparities in SA, including that of Singh et al, which found that from 1998 to 2011, Black patients had a lower utilization rate and longer median hospital stay than White patients after SA and that these disparities either remained the same or increased throughout this time. \( ^{8,25,26,29,31} \) Best et al found that Black patients had increased rates of complications and mortality compared to White patients from 2012 to 2018. \( ^{3} \) Our study further illustrates these disparities and how they persist in our novel CRS.

When considering the potential causes of the racial disparities identified in this study, it is worth noting that each of the comorbidities assessed has been studied for its relationship with the level of social support. In selecting these specific comorbidities that have been associated, in variable degrees, with social support, we have developed a strong prognostic indicator that is not inferior to other commonly used comorbidity scores currently described and utilized in the literature. Therefore, the possibility of social support potentially being a contributing factor to patient comorbidity load, and thus postoperative complication rate, cannot be eliminated. Although it is incredibly difficult to accurately assess a patient’s level of social support without in-depth interviewing and surveys, the assessment methods currently utilized are prohibitively resource-intensive and/or subjective measures that may introduce bias. \( ^{12,16,27} \) The CRS provides an objective measure to serve as an additional data point in patient care. This commonality among each of these factors may be an area for future study to further develop the understanding of racial disparities as it relates to social support, medical comorbidities, and complications related to TSA.

There were several limitations to this study. First, its retrospective nature is bound to the limits of the database fidelity and

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**Table IV**

Complication rate broken down by CRS score.

| Score | Complication rate (%) | N total | N percent (%) |
|-------|------------------------|---------|---------------|
| 0     | 12.3                   | 7960    | 30.7          |
| 1     | 19.2                   | 15600   | 60.2          |
| 2     | 29.6                   | 1249    | 4.8           |
| 3     | 33.1                   | 592     | 2.3           |
| 4     | 51.9                   | 420     | 1.6           |
| 5     | 57.3                   | 75      | 0.3           |
| 6     | 47.6                   | 21      | 0.1           |
| 7     | 77.8                   | 9       | 0.0           |
| 9     | 100.0                  | 1       | 0.0           |
| Total | 18.6                   | 25927   | 100.0         |

CRS, comorbidity risk score.
provides findings that cannot be established with the same degree of certainty as it would be in an ideal randomized control trial.  

The NSQIP also collects complications within a 30-day postoperative period, thus long-term complications could not be included. Furthermore, the variations in complication rate at a given CRS for each race may indicate involvement of additional factors that cannot be discerned from the given database and should be subjected to further investigation. Also, while primary SA complication rates vary in the literature, the complication rate may be considered higher than that in other studies; however, this was calculated from a national standardized data set. The average complication rate following primary SA is approximately 15%. The average CRS score in this study population was 0.8537 (CI 0.8011-0.8150, \( P < .05 \)). This correlates to a complication rate of approximately 18.54%, which is similar to the complication rate noted in the literature. To identify patients at significantly increased risk, those above 2 standard deviations should be recognized as significantly different from the mean. Two standard deviations above the mean CRS are approximately 2.47, which, when rounded to the nearest CRS, correlates to at least a 29.6% complication rate and identifies approximately 9.1% of the database population to be at increased risk of postoperative complications within 30 days. Despite these limitations, utilizing a large database such as NSQIP allows the proper identification of an at-risk population for complications utilizing risk factors such as the novel CRS described.

**Conclusion**

This study proposes a novel, straightforward comorbidity score with significant clinical utility and similar accuracy in predicting 30-day complications compared to prior indices such as the ASA, mCCI, and mFI, thus introducing a useful assessment that can be employed to improve risk assessments and potential costs of care in the age of bundled payments. The racial disparities discovered offer
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