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Predicting operative outcomes of total shoulder arthroplasty using the model for end-stage liver disease score

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Background: The aim of this study was to assess the efficacy of the Model for End-Stage Liver Disease (MELD) score in predicting postoperative complications following total shoulder arthroplasty (TSA).

Methods: The American College of Surgeons National Surgical Quality Improvement database was queried for all patients who underwent TSA between 2015 and 2019. The study population was subsequently classified into two categories: those with a MELD score $\geq$ 10 and those with a MELD score < 10. A total of 5265 patients undergoing TSA between 2015 and 2019 were included in this study. Among these, 4690 (89.1%) patients had a MELD score $\geq$ 10, while 575 (10.9%) patients had a MELD score < 10. Postoperative complications within 30 days of the TSA were collected. Multivariate logistic regression analysis was conducted to explore the correlation between a MELD score $\geq$ 10 and postoperative complications. The anchor based optimal cutoff was calculated by receiver operating characteristic analysis to determine the MELD score cutoff that most accurately predicts a specific complication. Youden's index (J) determined the optimal cutoff point calculation for the maximum sensitivity and specificity; these were deemed to be "acceptable" if the area under curve (AUC) was greater than 0.7 and "excellent" if greater than 0.8.

Results: Multivariate regression analysis found a MELD score $\geq$ 10 to be independently associated with higher rates of reoperation (OR, 2.08; $P = .013$), cardiac complications (OR, 3.37; $P = .030$), renal complications (OR, 7.72; $P = .020$), bleeding transfusions (OR, 3.23; $P < .001$), and nonhome discharge (OR, 1.75; $P < .001$). The receiver operating characteristic analysis showed that AUC for a MELD score cutoff of 7.61 as a predictor of renal complications was 0.87 (excellent) with sensitivity of 100.0% and specificity of 70.0%. AUC for a MELD score cutoff of 7.76 as a predictor of mortality was 0.76 (acceptable) with sensitivity of 81.8% and specificity of 71.0%.

Conclusion: A MELD score $\geq$ 10 was correlated with high rates of reoperation, cardiac complications, renal complications, bleeding transfusions, and nonhome discharge following TSA. MELD score cutoffs of 7.61 and 7.76 were effective in predicting renal complications and mortality, respectively.

Total shoulder arthroplasty (TSA) has demonstrated its efficacy in treating degenerative shoulder conditions. Over the past ten years, there has been a significant rise in the usage of both anatomic and reverse TSA.[4] In light of this growth, it is crucial to enhance preoperative risk stratification to optimize patient outcomes.

Previous research has employed various liver-related parameters to evaluate the risk of complications during and after surgery. Alone or in combination, aspartate transaminase, alanine transaminase, gamma-glutamyl transferase, alkaline phosphatase, bilirubin, and albumin have been utilized to assess postoperative liver function.[22] Notably, factors such as hyperbilirubinemia, elevated international normalized ratio (INR), hypoalbuminemia, and elevated creatinine have been linked to a higher risk of postoperative mortality.[27,28] Some studies have used the Child-Pugh-Turcotte scoring system to estimate the risk of postoperative complications; however, its clinical utility for

Institutional review board approval was not required for this study.

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orthopedic surgeons is limited due to the need for a multisystem subjective assessment of encephalopathy and ascites.[7,34]

The Model for End-Stage Liver Disease (MELD) score serves as a more objective and potentially more effective predictor of postoperative complications and mortality compared to the CPT system.[11] The MELD score is a more practical tool, given its relative simplicity and reliance on widely available laboratory values, namely bilirubin, INR, and creatinine.[16] To date, the impact of high MELD scores on TSA outcomes has not been investigated. Considering the established postoperative mortality risks associated with hyperbilirubinemia, elevated INR, and elevated creatinine, composite "MELD scores" of these risk factors could offer valuable insights for preoperative planning and risk stratification.

The aim of this study is to examine the relationship between MELD scores and postoperative complications following TSA. We hypothesize that a MELD score $\geq$ 10 is correlated with increased rates of mortality, readmission, and reoperation after TSA.

Methods

All patients who underwent either anatomic or reverse TSA between 2015 and 2019 were queried from the American College of Surgeons National Surgical Quality Improvement (NSQIP) database. As the NSQIP database is fully deidentified, this study was exempt from review and approval by our University's Institutional Review Board. Patient information included in the database is gathered from over 600 health-care facilities throughout the United States, obtained through various means such as interviews, outpatient visits, and examination of patient records.

Current Procedural Terminology code 23472 was used to identify 22,542 patients who underwent TSA from 2015 to 2019. We excluded patients from the analysis if they lacked preoperative serum creatinine, serum total bilirubin, or INR data. Similarly, those missing height/weight information, American Society of Anesthesiologists (ASA) classification, or functional health status were also removed from consideration. These exclusions left a total of 5265 cases for our statistical analysis (Fig. 1). For each subject, a MELD score was calculated using the following formula[20]:

$$\text{MELD} = 10 \times [(0.957 \times \ln(\text{serum creatinine})) + (0.378 \times \ln(\text{serum total bilirubin})) + (1.12 \times \ln(\text{INR})) + 0.643]$$

The study population was then stratified into two cohorts based on their MELD scores. 4690 (89.1%) patients had MELD scores $\geq$ 10 and 575 (10.9%) patients had MELD scores < 10.

Demographic data collected from the database included the following: race, gender, body mass index, age, smoking status, functional status, ASA physical status classification class, steroid use, preoperative laboratory values, preoperative comorbidities, and operative variables. We also collected complications occurring within 30 days after the operation. These included cardiac arrest requiring cardiopulmonary resuscitation, myocardial infarction, stroke or cerebrovascular accident, unplanned intubation, deep vein thrombosis, pulmonary embolism, requirement of mechanical ventilation >48 hours, acute renal failure, sepsis, septic shock, reoperation, readmission, mortality, deep incisional surgical site infection, organ/space surgical site infection, progressive renal insufficiency, urinary tract infection, pneumonia, postoperative

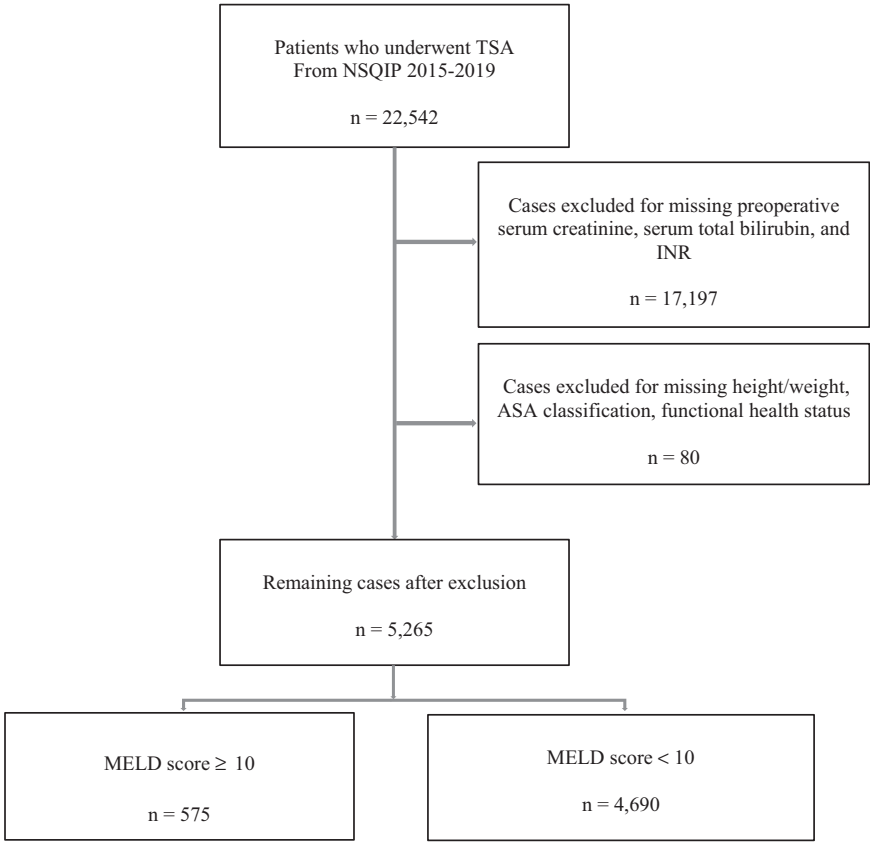

Figure 1 Strengthening the Reporting of Observational Studies in Epidemiology (*STROBE*) diagram with inclusion and exclusion criteria. *TSA*, total shoulder arthroplasty; *NSQIP*, National Surgical Quality Improvement Program; *ASA*, American Society of Anesthesiologists; *MELD*, Model for End-Stage Liver Disease; *INR*, international normalized ratio.

Table I
Univariate binomial logistic regression for patient demographics and comorbidities in both MELD score ≥ 10 and MELD score <10 groups.

Characteristic	MELD score ≥ 10		MELD score < 10		*P* value
	Number	Percent (%)	Number	Percent (%)	
Total	575	100	4690	100	
Age					
18-39	2	0.35	25	0.53	.557
40-64	106	18.44	1339	28.55	**<.001**
65-74	201	34.96	1899	40.49	.011
≥75	266	46.26	1427	30.43	**<.001**
Gender					**<.001**
Female	250	43.48	2756	58.76	
Male	325	56.52	1934	41.24	
Body mass index (kg/m^2)					
<18.5	2	0.35	39	0.83	.213
18.5-29.9	257	44.70	2253	48.04	.130
30-34.9	153	26.61	1260	26.87	.896
35-39.9	90	15.65	645	13.75	.215
≥40	73	12.70	493	10.51	.111
ASA classification					**<.001**
1-2	92	16.00	1906	40.64	
≥3	483	84.00	2784	59.36	
Functional status					**.009**
Independent	549	95.48	4568	97.40	
Dependent	26	4.52	122	2.60	
Smoking					.197
No	517	89.91	4131	88.08	
Yes	58	10.09	559	11.92	
Outpatient/inpatient					.296
Outpatient	30	5.22	297	6.33	
Inpatient	545	94.78	4393	93.67	
Diabetes					
No	387	67.30	3869	82.50	**<.001**
Noninsulin	113	19.65	605	12.90	**<.001**
Insulin	75	13.04	216	4.61	**<.001**
Dyspnea					
No	497	86.44	4315	92.00	**<.001**
Moderate exertion	75	13.04	361	7.70	**<.001**
At rest	3	0.52	14	0.30	.373
COPD					**.026**
No	512	89.04	4305	91.79	
Yes	63	10.96	385	8.21	
Ascites					**.002**
No	573	99.65	4689	99.98	
Yes	2	0.35	1	0.02	
Congestive heart failure					**<.001**
No	549	95.48	4661	99.38	
Yes	26	4.52	29	0.62	
Hypertension					**<.001**
No	105	18.26	1528	32.58	
Yes	470	81.74	3162	67.42	
Dialysis					**<.001**
No	554	96.35	4686	99.92	
Yes	21	3.65	4	0.09	
Disseminated cancer					**<.001**
No	566	98.44	4676	99.70	
Yes	9	1.57	14	0.30	
Chronic steroid use					**.002**
No	526	91.48	4437	94.61	
Yes	49	8.52	253	5.39	
Bleeding disorders					**<.001**
No	507	88.17	4573	97.51	
Yes	68	11.83	117	2.50	

ASA, American Society of Anesthesiologists; *COPD*, Chronic Obstructive Pulmonary Disease; *MELD*, Model for End-Stage Liver Disease.
Bold values indicate statistically significant values ($P < .05$).

anemia requiring transfusion within 72 hours after surgery, and superficial incisional surgical site infection.

SPSS Software version 26.0 (IBM Corporation, Armonk, NY, USA) was used to perform the statistical analyses for this investigation. Bivariate analysis was used to compare patient demographic characteristics, comorbidities, and surgical characteristics between cohorts. Multivariate logistic regression analysis was then conducted, with adjustments made for all significantly associated variables, such as patient demographics, preoperative comorbidities, and operative variables, to investigate the association between MELD scores ≥ 10 and postoperative complications. The calculated odds ratios (ORs) were reported with a 95% confidence interval. The level of statistical significance was set at $P < .05$.

Table II
Univariate binomial logistic regression of postoperative complications in both MELD score ≥ 10 and MELD score <10 groups.

Postoperative complication	MELD score ≥ 10		MELD score < 10		*P* value
	Number	Percent (%)	Number	Percent (%)	
Superficial SSI	1	0.17	15	0.32	.547
Deep SSI	0	0.00	3	0.06	.544
Organ space SSI	0	0.00	15	0.32	.174
Reoperation	18	3.13	68	1.45	**.003**
Wound dehiscence	0	0.00	4	0.09	.483
Stroke/CVA	0	0.00	8	0.17	.321
Cardiac complications	7	1.22	11	0.24	**<.001**
Respiratory complications	9	1.57	37	0.79	.059
Renal complications	3	0.52	3	0.06	**.002**
Urinary tract infection	9	1.57	29	0.62	**.011**
Bleeding transfusions	47	8.17	99	2.11	**<.001**
Deep vein thrombosis	0	0.00	13	0.28	.206
Sepsis/septic shock	3	0.52	6	0.13	**.031**
Readmission	31	5.39	151	3.22	**.007**
Mortality	4	0.70	7	0.15	**.007**
Nonhome discharge	129	22.45	537	11.45	**<.001**

SSI, surgical site infection; *CVA*, cerebrovascular accident; *MELD*, Model for End-Stage Liver Disease.
Bold values indicate statistically significant values ($P < .05$).

Results

Bivariate analysis was used to identify patient demographics and comorbidities associated with MELD scores ≥ 10, as shown in Table I. The characteristics of patients significantly associated with MELD scores ≥ 10 were age ≥ 75 ($P < .001$), male gender ($P < .001$), ASA ≥ 3 ($P < .001$), dependent functional status ($P = .009$), non-insulin dependent diabetes ($P < .001$), insulin dependent diabetes ($P < .001$), dyspnea at moderate exertion ($P < .001$), chronic obstructive pulmonary disease ($P = .026$), ascites ($P = .002$), congestive heart failure ($P < .001$), hypertension ($P < .001$), dialysis ($P < .001$), disseminated cancer ($P < .001$), chronic steroid use ($P = .002$), and bleeding disorder ($P < .001$).

Bivariate analysis was used to determine postoperative complications associated with MELD scores ≥ 10, as shown in Table II. The 30-day postoperative complications that were significantly associated with MELD scores ≥ 10 were reoperation ($P = .003$), cardiac complications ($P < .001$), renal complications ($P = .002$), urinary tract infection ($P = .011$), bleeding transfusions ($P < .001$), sepsis/septic shock ($P = .031$), readmission ($P = .007$), mortality ($P = .007$), and nonhome discharge ($P < .001$).

After adjusting for all significantly associated patient variables, multivariate logistic regression identified the 30-day postoperative complications associated with MELD scores ≥ 10, as shown in Table III. Multivariate analysis revealed that MELD scores ≥ 10 were independently associated with higher reoperation rates (OR, 2.08; $P = .013$), cardiac complications (OR, 3.37; $P = .030$), renal complications (OR, 7.72; $P = .020$), bleeding transfusions (OR, 3.23; $P < .001$), and nonhome discharge (OR, 1.75; $P < .001$).

Table III
Multivariate binomial logistic regression of significant postoperative complications, adjusted for all statistically significant demographics and comorbidities.

Postoperative complications	Odds ratio	95% CI	*P* value
Reoperation	2.08	1.17-3.72	**.013**
Cardiac complications	3.37	1.13-10.09	**.030**
Renal complications	7.72	1.38-43.36	**.020**
Urinary tract infection	2.28	0.99-5.25	.053
Bleeding transfusions	3.23	2.15-4.86	**<.001**
Sepsis/septic shock	3.62	0.74-17.80	.113
Readmission	1.31	0.84-2.04	.227
Mortality	3.24	0.75-14.00	.116
Nonhome discharge	1.75	1.35-2.26	**<.001**

CI, confidence interval.
Bold values indicate statistically significant values ($P < .05$).

Receiver operating characteristic analysis was performed to determine the MELD score cutoff that most accurately predicts a specific complication, as shown in Table IV. Area under curve (AUC) for a MELD score cutoff of 7.61 as a predictor of renal complications was 0.87 (excellent) with sensitivity of 100.0% and specificity of 70.0% (Fig. 2). AUC for a MELD score cutoff of 7.76 as a predictor of mortality was 0.76 (acceptable) with sensitivity of 81.8% and specificity of 71.0% (Fig. 3). AUC for a MELD score cutoff as a predictor of other complications (reoperation, cardiac complications, bleeding transfusions, sepsis/septic shock, readmission, and nonhome discharge) was below 0.7.

Discussion

This study used a national database to identify a MELD of score ≥ 10 as an independent predictor of reoperation, cardiac complications, renal complications, bleeding transfusions, and nonhome discharge following TSA. In addition, we found that a specific MELD score cutoff can be used as an excellent predictor for postoperative renal complications and another MELD score cutoff is an acceptable predictor for postoperative mortality. These findings indicate that the MELD score may prove to be a crucial resource for orthopedic surgeons when it comes to stratifying risk and managing patients before they undergo TSA.

The importance of preoperative risk stratification in TSA is well-recognized, especially as it has become increasingly favored for elective treatment of degenerative shoulder diseases. TSA has proven particularly effective for elderly patients who often face more complex medical conditions.[2,12] The identification and management of modifiable risk factors prior to surgery can reduce both hospital length of stay and costs, improve surgical planning, and improve interdisciplinary communication, thereby optimizing postoperative outcomes.[19]

The CPT scoring system was initially implemented to assess the severity of cirrhosis and identify patients suitable for hepatic resection.[13] However, the more recently developed MELD score provides an evaluation of liver function reserve in patients with cirrhosis.[14,20,26] It utilizes three easily measurable and objective parameters that are routinely obtained prior to surgical

Table IV
Results of ROC analysis.

Postoperative complications	AUC (95% CI)	Youden's index	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	PLR	NLR	DOR
Reoperation	0.62 (0.56-0.68)	7.95	48.8	72.9	85.0	57.0	1.80	0.73	2.47
Cardiac complications	0.63 (0.48-0.79)	8.14	61.1	74.0	72.0	80.0	2.35	0.51	4.61
Renal complications	**0.87 (0.73-1.00)**	7.61	100.0	70.0	61.0	100.0	3.33	0.00	Inf
Bleeding transfusions	0.66 (0.61-0.71)	7.86	53.0	72.7	88.0	68.0	1.95	0.17	11.47
Sepsis/septic shock	0.63 (0.42-0.83)	7.47	66.7	61.0	66.0	61.0	1.71	0.56	3.04
Readmission	0.59 (0.55-0.63)	6.98	63.0	54.2	63.0	54.2	1.37	0.62	2.20
Mortality	**0.76 (0.64-0.88)**	7.76	81.8	71.0	69.0	83.0	2.83	0.26	10.85
Nonhome discharge	0.58 (0.55-0.60)	7.85	39.7	73.4	82.0	74.0	1.49	0.76	1.97

AUC, area under the curve; *CI*, confidence interval; *PPV*, positive predictive value; *NPV*, negative predictive value; *PLR*, positive likelihood ratio; *NLR*, negative likelihood ratio; *DOR*, diagnostic odds; *Inf*, infinite; *ROC*, receiver operating characteristics.
Bold values indicate statistically significant values ($P < .05$).

procedures; creatinine, INR, and total bilirubin. The MELD score has been deemed superior to the CPT score as it includes serum creatinine measurements, providing a more comprehensive overview of total body health.[32] In addition, the MELD score has been shown to predict survival for patients with cirrhosis who are undergoing a transjugular intrahepatic portosystemic shunt,[20] aid in determining priority on liver transplantation waitlists, and predict outcomes for cirrhotic patients after surgery.[14,26]

Our study results indicate that a high MELD score independently increases the risk of blood transfusions following TSA. As the MELD score assesses liver function, with INR as one of the three components used in its calculation, a high MELD score often indicates poor liver synthetic function and reduced ability to coagulate blood, which may result in excessive bleeding during the perioperative period. Contributing factors to hepatic coagulopathy include reduced synthesis of coagulation factors, deficient vitamin K levels, and thrombocytopenia due to bone marrow suppression or splenic sequestration related to portal hypertension.[29] Existing literature clearly represents the association between postoperative bleeding and liver function. For example, Szapary and colleagues found that patients with MELD scores above 9 were over five times more likely to require blood transfusions following hip fracture surgery.[31]

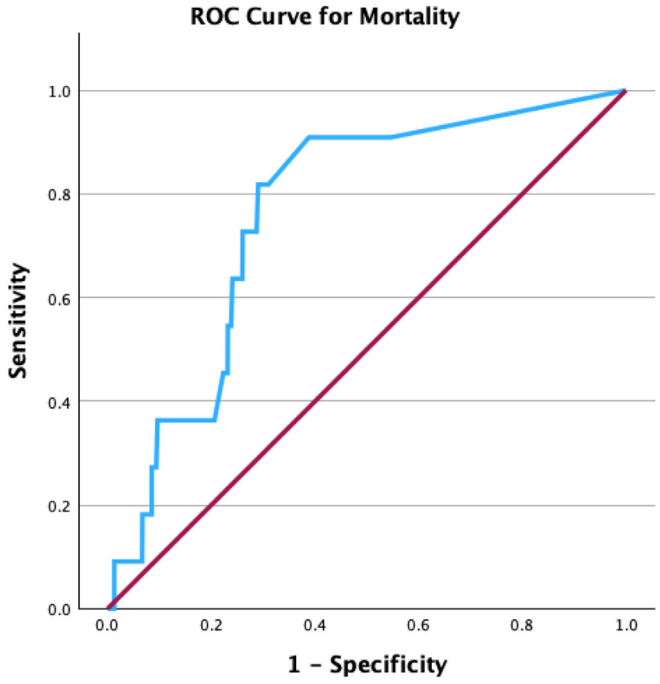

Figure 2 The area under the receiver operating characteristics (*ROC*) for Mortality.

Similarly, Shi and colleagues discovered that a MELD score higher than 10 is associated with an increased risk of transfusion in patients undergoing surgery for proximal humerus fractures.[30] Chakravorty and colleagues also identified liver disease as a significant risk factor for postoperative blood transfusions in posterior lumbar fusion cases.[6] In this study, we extend this correlation to TSA, a procedure typically performed in elective or nonemergency settings. Therefore, preoperative enhancements prior to shoulder arthroplasty could help to reduce patient risk profiles connected to coagulopathy. Interventions such as vitamin K supplementation and transfusion of fresh frozen plasma or platelets can be employed to rectify coagulopathy associated with liver dysfunction.[1]

Our study also found that a high MELD score was associated with an increased susceptibility to renal complications. Multiple factors can contribute to postoperative renal failure in patients with liver disease. These include exposure to nephrotoxic medications like diuretics or nonsteroidal anti-inflammatory drugs, urinary tract infections, spontaneous bacterial peritonitis, gastrointestinal bleeding, and hepatorenal syndrome.[3,21] Specifically, fluid shifts and changes in vascular volume during anesthesia place susceptible patients at a higher risk for hepatorenal syndrome, which presents as azotemia and oliguria.[5] Deleuran et al demonstrated that postoperative renal failure rates were higher among cirrhosis patients who had undergone THA or TKA.[9] Tiberi et al also found that patients with cirrhosis had higher rates of urinary tract infections and renal failure within 90 days after THA and TKA.[34] Maintaining optimal hydration status throughout the perioperative phase and minimizing the use of potentially nephrotoxic drugs could potentially improve patient outcomes following shoulder arthroplasty.[25] Furthermore, our study found that a MELD score cutoff of 7.61 can serve as an excellent predictor of renal complications after TSA.

Additionally, patients with MELD scores $\geq$ 10 were found to be at an escalated risk for experiencing cardiac complications, including cardiac arrest or myocardial infarction. Hyperdynamic syndrome is a widely recognized condition often associated with cirrhosis patients.[8,18,24] It typically presents with an increased heart rate and cardiac output, alongside reduced systemic vascular resistance and arterial blood pressure.[23] Past studies have indicated that sudden fluctuations in the rhythm and intensity of cardiac contractions can intensify cardiac stress and oxygen requirements, which may ultimately result in an infarction.[33]

Another crucial finding from our study is that a MELD score cutoff of 7.76 could serve as an acceptable threshold to predict all-cause mortality within 30 days following TSA. In a prior study, Teh et al identified the MELD score as the most potent long-term predictor of mortality in cirrhotic patients after major surgery.[32] Hundersmarck et al assessed 90-day, 1-year, and 2-year mortality rates in patients with chronic liver disease who underwent hip fracture surgery and found that an increasing MELD score was associated with higher

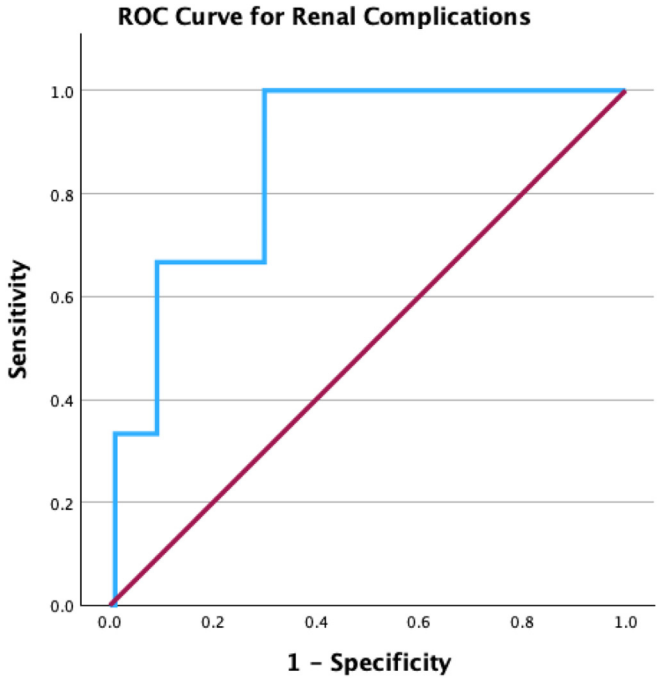

Figure 3 The area under the receiver operating characteristics (*ROC*) for Renal Complications.

mortality rates.[15] Finally, Shi et al discovered that a MELD score higher than 10 is associated with a higher risk of death in patients undergoing surgery for proximal humerus fractures.[30] Our findings build upon this by demonstrating that MELD scores can function as a practical and effective instrument for orthopedic surgeons to stratify mortality risk specifically in TSA patients.

Limitations

There are some key limitations related to data collection and study design that warrant further investigation. The data collection timeframe within the American College of Surgeons NSQIP database spans only up to 30 days postsurgery, thereby excluding any long-term surgical complications. Consequently, this study does not account for such complications, which may impact a significant portion of the TSA patient population over time. Moreover, this paper does not consider possible preoperative anticoagulation and usage of medications that could affect renal or hepatic function since these data were not immediately available in the ACS NSQIP database. Nevertheless, the principal strength of our study is its robust sample size, which facilitated the detection of relationships between MELD score and less common postoperative complications, such as renal and cardiac complications. It has also been shown in the literature that the robustness of the NSQIP database is superior to other national databases in terms of consistency, completion of data input, and accuracy.[10,17,35] Furthermore, this study was able to adjust for many comorbidities and patient characteristics in our multivariate analysis. Lastly, this study has broad implications to the preoperative screening and optimization of patients undergoing shoulder arthroplasty.

Future directions

Surgeons and health-care providers should consider evaluating the MELD score in addition to other relevant clinical factors when determining a patient's suitability for TSA. For future studies, exploring interventions or strategies to mitigate the increased risk associated with poor liver function in TSA patients should be a priority. Additionally, focusing on the investigation of long-term follow-up data is crucial for strengthening the evidence base.

Conclusion

A MELD score $\geq$ 10 was correlated with higher rates of reoperation, cardiac complications, renal complications, bleeding transfusions, and nonhome discharge following TSA. In addition, MELD score cutoffs of 7.61 and 7.76 predicted renal complications and mortality, respectively. Understanding the association between MELD scores and postoperative complications following TSA can better prepare physicians in their perioperative risk stratification as part of the patient selection process for TSA.

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Supplementary Data

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