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Efficacy of the modified Frailty Index and the modified Charlson Comorbidity Index in predicting complications in patients undergoing operative management of proximal humerus fracture

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Background: Comorbidity indices such as the 5-factor modified Frailty Index (mFI-5) and modified Charlson Comorbidity Index (mCCI) are widely used in outcomes research.

Methods: A total of 3893 patients who underwent total shoulder arthroplasty (n=975), hemiarthroplasty (n=495), or open reduction and internal fixation (n=2423) for the treatment of proximal humerus fracture from 2005-2017 were identified from the National Surgical Quality Improvement Program database. Data regarding demographics, comorbidities, American Society of Anesthesiologists class, and postoperative complications were collected, and the mFI-5 and mCCI were calculated for each case. Multivariate logistic regression models and receiver operating characteristic curve analyses were performed.

Results: The patient population had a mean age of 68.0 ± 13.2 years, body mass index of 29.1 ± 8.1 and mean operative time of 119.9 ± 55.5 minutes. The most common complications within this cohort were extended length of stay (4 days or more) (1085/3893; 27.87%), transfusion (377/3893; 9.68%), unplanned reoperation (97/3893; 2.49%), urinary tract infection (43/3893; 1.10%), death (42/3893; 1.08%), and deep vein thrombosis (40/3893; 1.03%). After accounting for patient demographics, the mFI-5 (odds ratio [OR] = 1.105, $P < .001$) and mCCI (OR = 1.063, $P < .001$) were significantly associated with incidence of any adverse event. Both comorbidity indices had low positive predictive value and high negative predictive value for all adverse events.

Conclusion: The comorbidity indices mCCI and mFI-5 are both strongly associated with adverse events but have moderate ability to predict complications following surgical treatment of proximal humerus fractures.

Institutional review board approval was not required for this prognosis study.

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Proximal humerus fractures represent 5.03%[17] to 5.7%[1] of all fractures, with an incidence of 6.0 per 10,000 person-years.[8] Because of its association with the elderly population, proximal humerus fractures are associated with significant complication rates and mortality.[14] Operative management for proximal humerus fracture includes open reduction and internal fixation, total shoulder arthroplasty, and hemiarthroplasty. For a given treatment modality, proximal humerus fracture is associated with a higher risk of complications.[12] Thus, there is a need for better understanding of complication risk to allocate resources effectively and to optimize treatment outcomes.

Comorbidity indices, such as the 5-factor modified Frailty Index (mFI-5),[25] the modified Charlson Comorbidity Index (mCCI),[5] and the American Society of Anesthesiologists classification (ASA class),[4] may be a method of risk stratification of postoperative complications because of their efficiency, ease of collection, and predictive accuracy.[23] Several studies have looked at the ability of mFI-5, mCCI, and ASA class to predict complications following surgical treatment for a variety of conditions, including posterior lumbar fusion,[15] spinal deformity,[28] and spine tumor.[11]

These comorbidity indices have also been used to predict complications following hip fracture surgery,[25] revision total hip arthroplasty,[10] and shoulder surgery.[21] Given the abundance of studies that demonstrate their predictive value, it is clear that comorbidity indices can be used to adequately assess a patient's risk for postoperative complications. Thus, comorbidity indices may be used as a tool to help guide clinical decision making. This is particularly important when dealing with proximal humerus fractures, because there exists some controversy over the optimal outcomes of operative vs. nonoperative treatment. Several randomized controlled trials have shown no difference in complication rates.[6,18,27]

The current trend of health care is moving toward value-based care, and reimbursements are decreasing for complications and readmissions within 30 days of the index procedure. Thus, the purpose of this study is to evaluate the ability of mFI-5 and mCCI to predict complications following surgical treatment of proximal humerus fractures. We hypothesize that both the mFI-5 and the mCCI will predict postoperative adverse events such as surgical site infections, deep vein thrombosis, unplanned reoperations, and extended hospital length of stay.

Materials and methods

This study is a retrospective analysis of data acquired from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP). ACS-NSQIP is an outcomes-based, quality improvement program that collects clinical information on surgical cases, with 714 participating hospitals. The ACS-NSQIP database includes data from 270 different variables, including demographics, comorbidities, lab values, and postoperative complications within 30 days of the specified procedure. This risk-adjusted data are collected by trained clinical reviewers and undergoes periodic quality assurance measures, such as random biweekly audits, to ensure the reliability of the data.[2,26]

The patient population was selected using Current Procedural Terminology (CPT) and International Classification of Diseases, 9th Revision (ICD-9) and 10th Revision (ICD-10), codes. Patients were included in the study if they underwent shoulder arthroplasty (CPT: 23472), shoulder hemiarthroplasty (CPT: 23470), or open reduction and internal fixation (CPT: 23615) between 2005 and 2017 for the treatment of proximal humerus fracture. Patients with missing variables (denoted "Unknown," "NULL," "None assigned," "None," or "Other" in ACS-NSQIP database) were removed from the population.

Patient demographics including age, sex, body mass index, and ASA class were collected. An ASA class greater than 3 corresponded to severe systemic disease (new classification of physical status). The mFI-5 score for each patient was calculated assessing the following variables: diabetes mellitus, congestive heart failure, chronic obstructive pulmonary disease, hypertension requiring medication, and functional status. One point was assigned to each of these variables; if the patient was positive for a given category, they were assigned 1, and if negative, 0. The sum of the 5-point values was determined to be the mFI-5 score. The mCCI score was also calculated for each patient in a similar manner. However, unlike the mFI-5, the mCCI has varying point values for its 11 items. The definitions of ASA class, mFI-5, and mCCI are shown in Table I.

Adverse events that were measured included: death, surgical site infection, renal complications, sepsis, intubation, transfusion, pneumonia, urinary tract infection, cardiac arrest requiring CPR), deep vein thrombosis, unplanned reoperation, and extended length of stay. Extended length of stay was defined as a hospital length of stay greater than or equal to 4 days, which was the 75th percentile of our population.

Statistical analyses were performed using the software RStudio software version 1.0.143 (R Foundation for Statistical Computing, Vienna, Austria). Receiver operating characteristic (ROC) curves were generated for mFI-5, mCCI, and ASA class against adverse events. Area under the curve (AUC), which represents the

Table I Comorbidity index definitions

American Society of Anesthesiologists (ASA) classification		Modified Frailty Index (mFI-5)		Modified Charlson Comorbidity Index (mCCI)	
Category	Description	Points	Description	Points	Description
I	A normal healthy patient. Example: Fit, nonobese (BMI under 30), a nonsmoking patient with good exercise tolerance.	1	Congestive heart failure	1	Cerebrovascular disease
II	A patient with a mild systemic disease. Example: Patient with no functional limitations and a well-controlled disease (eg, treated hypertension, obesity with BMI under 35, frequent social drinker, or is a cigarette smoker).	1	Diabetes mellitus	1	Chronic pulmonary disease
III	A patient with a severe systemic disease that is not life-threatening. Example: Patient with some functional limitation as a result of disease (eg, poorly treated hypertension or diabetes, morbid obesity, chronic renal failure, a bronchospastic disease with intermittent exacerbation, stable angina, implanted pacemaker).	1	History of COPD or current pneumonia	1	Congestive heart failure
IV	A patient with a severe systemic disease that is a constant threat to life. Example: Patient with functional limitation from severe, life-threatening disease (eg, unstable angina, poorly controlled COPD, symptomatic CHF, recent (less than 3 mo ago) myocardial infection or stroke).	1	Hypertension requiring medication	1	Myocardial infarction
V	A moribund patient who is not expected to survive without the operation. The patient is not expected to survive beyond the next 24 h without surgery. Examples: ruptured abdominal aortic aneurysm, massive trauma, and extensive intracranial hemorrhage with mass effect.	1	Nonindependent functional status	1	Peripheral vascular disease
VI	A brain-dead patient whose organs are being removed with the intention of transplanting them into another patient.			2	Diabetes
				2	Hemiplegia
				2	Renal disease
				2	Tumor without metastases
				3	Liver disease
				6	Metastatic solid tumor

BMI, body mass index; *COPD*, chronic obstructive pulmonary disease; *CHF*, congestive heart failure.

predictive ability of the test, was calculated for each ROC curve. AUC values can fall between 0 and 1, with higher values indicating a more accurate test. An AUC of 0.5 suggests the test has no discriminative ability, 0.7-0.8 is considered acceptable, 0.8-0.9 is considered excellent, and an AUC greater than 0.9 is considered outstanding.[13] Positive and negative predictive values were calculated for mFI-5 and mCCI, for each of the 12 adverse events. Univariate and multivariate logistic regression models were performed to compare the predictive abilities of age, body mass index, ASA class, mFI-5, and mCCI on postoperative complications.

Results

A total of 3893 patients were included in the final population for this study. The mean age of the population was 68.0 ± 13.2 years, mean body mass index was 29.1 ± 8.1, and mean operative time was 119.9 ± 55.5 minutes. Within this population, 2423 patients underwent open reduction and internal fixation, 975 patients underwent total shoulder arthroplasty, and 495 patients underwent hemiarthroplasty (Table II).

The most common complications within this cohort were extended length of stay (4 days or more) (n=1085), transfusion (n=377), unplanned reoperation (n=97), urinary tract infection (n=43), death (n=42), and deep vein thrombosis (n=40) (Table III). The mean length of stay was 3.43 ± 7.29 days.

Univariate analysis of each of the 3 comorbidity indices, mFI-5 (1.105, 95% CI: [1.087-1.124]; $P < .001$), mCCI (1.063, 95% CI: [1.048-1.079]; $P < .001$), and ASA class (1.214, 95% CI: [1.187-1.240]; $P < .001$), were predictive of any adverse event.

Analysis of the ROC curves demonstrated that among all adverse events, mFI-5 was most predictive of renal complications (AUC 0.878) and cardiac arrest requiring CPR (AUC 0.802) (Fig. 1; Table IV). ROC analysis of mCCI showed similar results; mCCI was most predictive of renal

Table II Patient demographics

Characteristic	Mean ± SD or n (%)
Demographics	
Age, yr	68.0 ± 13.2
BMI	29.1 ± 8.1
Sex	
Male	872 (22.4)
Female	3021 (77.6)
Comorbidities	
Functional status	
Independent	3626 (93.1)
Partially dependent	237 (6.1)
Totally dependent	30 (0.8)
Current smoker (within 1 yr)	
Yes	665 (17.1)
No	3228 (82.9)
Diabetes mellitus requiring therapy with noninsulin agents or insulin	
No	3053 (78.4)
Noninsulin	464 (11.9)
Insulin	353 (9.1)
Oral	23 (0.6)
Congestive heart failure (within 30 d prior to surgery)	
Yes	43 (1.1)
No	3850 (98.9)
Dialysis	
Yes	18 (0.5)
No	3875 (99.5)
Ascites (within 30 d prior to surgery)	
Yes	2 (0.1)
No	3891 (99.9)
Disseminated cancer	
Yes	22 (0.6)
No	3871 (99.4)
Hypertension requiring medication	
Yes	2310 (59.3)
No	1583 (40.7)
Dyspnea	
At rest	23 (0.6)
Exertional	217 (5.6)
No	3653 (93.8)
Acute renal failure	
Yes	9 (0.2)
No	3884 (99.8)
Steroid use for chronic condition	
Yes	146 (3.8)
No	3747 (96.2)
Bleeding disorder	
Yes	208 (5.3)
No	3685 (94.7)
Weight loss (>10% of body weight in last 6 mo)	
Yes	16 (0.4)
No	3877 (99.6)
Laboratory values	
Hematocrit (%)	36.3 ± 5.0
Creatinine (mg/dL)	0.91 ± 0.6
WBC ($\times 10^9$ cells/L)	9.0 ± 3.1
Platelets ($\times 10^9$ cells/L)	253.8 ± 84.9
Sodium (mEq/L)	137.7 ± 3.3
Intraoperative	
ASA classification	
1	146 (3.8)
2	1426 (36.6)
3	2086 (53.6)
4	235 (6.0)
mFI-5	
0	1346 (34.6)
1	1582 (40.6)
2	804 (20.7)
3	135 (3.5)
4	25 (0.6)
5	1 (0.0)
mCCI	
0	2779 (71.4)
1	241 (6.2)
2	741 (19.0)
3	95 (2.4)
4	11 (0.3)
5	4 (0.1)
6	14 (0.4)
7	3 (0.1)
8	5 (0.1)
Operative time (min)	119.9 ± 55.5
Procedure	
ORIF	2423 (62.2)
TSA	975 (25.0)
Hemi	495 (12.7)
Anesthesia	
Epidural	2 (0.1)
General	3779 (97.1)
Local	1 (0.0)
MAC/IV	38 (1.0)
Regional	64 (1.6)
Spinal	9 (0.2)

(*continued on next column*)

(*continued*)

BMI, body mass index; *WBC*, white blood cell; *ASA*, American Society of Anesthesiologists; *mFI-5*, 5-factor modified Frailty Index; *mCCI*, modified Charlson Comorbidity Index; *ORIF*, open reduction and internal fixation; *TSA*, total shoulder arthroplasty; *MAC/IV*, monitored anesthesia care / intravenous; *SD*, standard deviation.

complications (AUC 0.906) and cardiac arrest requiring CPR (AUC 0.763) (Fig. 1; Table IV). Interestingly, ASA class was most predictive of sepsis (AUC 0.756), death (AUC 0.749), and cardiac arrest requiring CPR (AUC 0.717) (Fig. 1; Table IV). Positive predictive value was low and negative predictive value was high for all complications in all 3 comorbidity indices (Table V).

Table III Patient complications

Complication	Count (n)	Incidence (%)
Death	42	1.08
Surgical site infection	29	0.74
Renal complications	10	0.26
Sepsis	21	0.54
Intubation	28	0.72
Transfusion	377	9.68
Pneumonia	32	0.82
Urinary tract infection	43	1.10
Cardiac arrest requiring CPR	10	0.26
Deep vein thrombosis	40	1.03
Unplanned reoperation	97	2.49
Extended length of stay	1085	27.87
Any adverse event	1313	33.73

CPR, cardiac pulmonary resuscitation.

Multivariate analysis of the comorbidity indices mFI-5 and mCCI was performed for any adverse event to account for other confounding variables. An increase in mFI-5 resulted in an increased likelihood of any adverse event (odds ratio [OR] 1.039. 95% confidence interval [CI] 1.019-1.058; $P < .001$), whereas an increase in mCCI resulted in a slightly smaller increase in likelihood of any adverse event (OR 1.032, 95% CI 1.016-1.047; $P < .001$). For minor complications (transfusion or extended length of stay), both increased mFI-5 (OR 1.049, 95% CI 1.025-1.074; $P < .001$) and increased mCCI (OR 1.048, 95% CI 1.017-1.080; $P < .001$) had an increased likelihood of minor complications. For major complications (death, myocardial infarction, infection, and unplanned return to OR), both increased mFI-5 (OR 1.020, 95% CI 1.003-1.037; $P < .05$) and mCCI (OR 1.033, 95% CI 1.012-1.054; $P < .001$) were associated with an increased likelihood of major complications. Of note, increased severity of the ASA classification was not significantly associated with an increased likelihood of major complications ($P = .92$) (Tables VI-VIII).

Discussion

This study was an analysis of surgical cases for the treatment of proximal humerus fracture, using data acquired from the ACS-NSQIP database. We found that all 3 comorbidity indices, mFI-5, mCCI, and ASA class, were only moderate predictors of postoperative complications at best. Among the 3, ASA class had the highest discriminative ability for all adverse events overall, followed by mFI-5 and mCCI. The results of the present study suggest that the comorbidity indices mFI-5 and mCCI have limited ability to predict complications following surgical management of proximal humerus fracture, unlike in a similar cohort of hip fractures.[25] They may, however, have value as screening tools.

Notably, in contrast to previous investigations that demonstrated that mFI-5 and mCCI were good predictors of postoperative complications,[11,23,28] mFI-5 and mCCI were mediocre predictors of postoperative complications. There are a number of possible contributory factors that are well described by Fu et al.[5] The mFI-5 and mCCI indices are calculated based on variables reported from the patient's medical history. Therefore, any incorrect information or missing data may affect these indices. The NSQIP database has evolved over time, and changes in its coding have resulted in missing data for several variables included in these comorbidity indices.[22] Additionally, the method in which these missing values are treated significantly affects the mFI-5 and mCCI.[22] In our study, for patients who were not coded as having a certain condition in NSQIP, it was assumed that they did not have that condition. However, as Shultz et al suggests, treating conditions for which data were missing as not present may result in markedly different mFI-5 and mCCI values than if those patients with missing data were dropped from the study population.[22] Furthermore, variables included in comorbidity indices may not be sensitive enough to adequately capture the lower comorbidity burden in patients undergoing elective orthopedic procedures, relative to other surgical indications.[5] This theory is supported by the floor effect observed with our mCCI values; 71.4% of the study population had an mCCI of 0, suggesting there may be other variables that are not being accounted for in the mCCI that may be more appropriate for our specific population. This is consistent with the findings of Fu et al, which reported that 77% of its cohort had an mCCI of 0.[5]

In comparison to the mFI-5 and mCCI, ASA class was a much better predictor of postoperative complications. However, there are a number of limitations associated with ASA class. The ASA classification is inherently a subjective measure, and studies have raised concerns about its inter-rater reliability between anesthesiologists[19,20,24] and among providers of different specialties.[9] It has also been demonstrated that the ASA classification system is dependent on one's experience.[3] Moreover, there have been multiple amendments to the ASA classification system, which resulted in conflicting definitions of ASA classes, and inconsistent usage in the literature.[7] Despite these limitations, ASA class was more predictive of postoperative complications than the mFI-5 and mCCI comorbidity indices. ASA class is a measure of the patient's general, preoperative physiological fitness, with a higher ASA class indicating worse physical status. It is largely based on the extent of systemic disease as well as the degree of necessity for surgery because of their condition. Intuitively, patients with a higher ASA class have a higher risk of morbidity and mortality, which results in a higher incidence of postoperative complications. A counterargument to ASA class

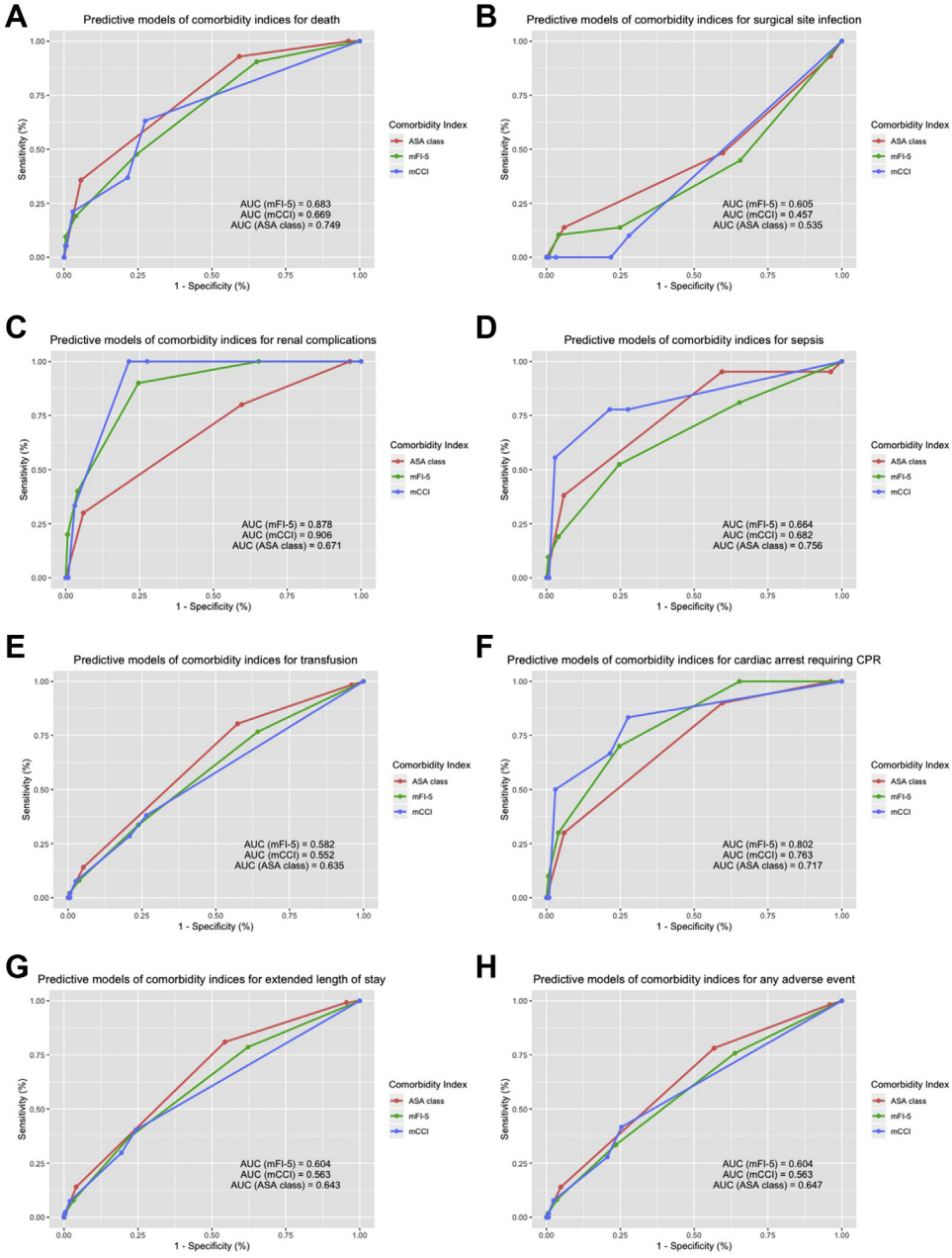

Figure 1 Predictive models of comorbidity indices mFI-5, mCCI, and ASA class.

as a predictor of complication risk, according to Owens,[16] is that the type of procedure is not accounted for in the ASA classification system; a patient is still in the same ASA class regardless of whether he or she is undergoing excision of a skin lesion with monitored anesthesia or pancreatectomy with general anesthesia. Operative risk is different depending on the nature of the surgery, but the physical condition of the patient is the same preoperatively.[16] However, in the context of the present study, our patient population underwent surgery for a common indication. Therefore, the variation in operative risk due to the type of surgery alone may have been relatively low, resulting in a greater observed association between ASA class and postoperative adverse events.

In our study, mFI-5 was not found to be a strong predictive factor for postoperative complications, whereas in the hip fracture cohort in Traven et al,[25] it was an excellent predictive factor. The differences in population age may have contributed to these differences in predictive ability; the population in Traven et al[25] was significantly older, and thus any effects of comorbidities on postoperative complications may have been magnified. Furthermore, the

Table IV Summary of receiver operating characteristic curve analysis

Adverse event	mFI-5		mCCI		ASA class	
	Threshold	AUC (%)	Threshold	AUC (%)	Threshold	AUC (%)
Death	0.5	68.3 (61.2-76.0)	0.5	66.9 (59.1-74.8)	2.5	74.9 (68.7-81.1)
Surgical site infection	0.5	60.5 (50.2-70.8)	2.5	45.7 (38.2-53.3)	2.5	53.5 (42.3-64.6)
Renal complications	1.5	87.8 (79.6-96.0)	1.5	90.6 (87.2-93.9)	3.5	67.1 (50.2-84.1)
Sepsis	1.5	66.4 (53.8-78.9)	1.5	68.2 (55.8-80.7)	2.5	75.6 (66.0-85.1)
Intubation	0.5	56.6 (47.0-66.1)	0.5	62.7 (53.5-71.9)	2.5	63.5 (55.2-71.7)
Transfusion	0.5	58.2 (55.4-61.1)	0.5	55.2 (52.6-57.9)	2.5	63.5 (61.0-66.0)
Pneumonia	1.5	68.4 (58.9-77.8)	0.5	65.4 (56.5-74.3)	2.5	68.2 (60.7-75.7)
Urinary tract infection	0.5	55.6 (48.7-62.6)	2.5	48.7 (41.8-55.6)	2.5	58.5 (51.5-65.5)
Cardiac arrest requiring CPR	1.5	80.2 (68.9-91.6)	0.5	76.3 (61.8-90.8)	2.5	71.7 (57.8-85.5)
Deep vein thrombosis	1.5	51.4 (42.9-59.9)	0.5	64.7 (57.2-72.1)	2.5	50.4 (43.0-57.7)
Unplanned reoperation	0.5	51.1 (45.8-56.4)	2.5	50.7 (46.0-55.5)	2.5	52.9 (47.6-58.1)
Extended length of stay	0.5	60.4 (58.6-62.3)	0.5	56.3 (54.7-58.0)	2.5	64.3 (62.6-66.0)
Any adverse event	0.5	60.4 (58.7-62.2)	0.5	56.3 (54.7-57.9)	2.5	64.7 (63.1-66.3)

CPR, cardiac pulmonary resuscitation; *mFI-5*, 5-factor modified Frailty Index; *AUC*, area under the curve; *mCCI*, modified Charlson Comorbidity Index; *ASA*, American Society of Anesthesiologists.

Table V Comparison of positive and negative predictive values for mFI-5, mCCI, and ASA class

Adverse event	mFI-5		mCCI		ASA class	
	PPV (%)	NPV (%)	PPV (%)	NPV (%)	PPV (%)	NPV (%)
Death	1.49	99.70	2.33	99.42	1.68	99.81
Surgical site infection	1.19	99.49	1.52	99.28	0.95	99.40
Renal complications	0.93	99.97	1.15	100.00	1.28	99.81
Sepsis	1.14	99.66	1.37	99.70	0.86	99.94
Intubation	0.86	99.55	1.44	99.57	0.99	99.68
Transfusion	11.35	93.46	12.66	91.51	13.05	95.29
Pneumonia	1.87	99.52	1.71	99.53	1.21	99.75
Urinary tract infection	1.37	99.41	2.27	98.94	1.38	99.30
Cardiac arrest requiring CPR	0.73	99.90	0.72	99.93	0.39	99.94
Deep vein thrombosis	1.14	99.01	2.24	99.46	1.12	99.11
Unplanned reoperation	2.63	97.77	5.30	97.61	2.63	97.71
Extended length of stay	32.55	80.98	36.36	75.53	36.15	84.35
Any adverse event	39.14	76.52	43.36	70.13	43.17	80.22

CPR, cardiac pulmonary resuscitation; *mFI-5*, 5-factor modified Frailty Index; *mCCI*, modified Charlson Comorbidity Index; *ASA*, American Society of Anesthesiologists; *PPV*, negative predictive value; *NPV*, negative predictive value.

mortality rate of the current study population was 1.08%; in Traven et al, the mortality rate was 6.6%.[25] This may be explained by the fact that hip fracture limits the patient's ability to ambulate and perform activities of daily living, thus further exacerbating comorbidities, which results in higher risk of mortality. Moreover, it is likely that surgeons subconsciously prefilter patients with proximal humerus fractures; if patients are too sick to begin with, they are not offered surgery and managed nonoperatively. On the other hand, hip fractures always require surgery, which translates to higher complication rates. As a result, these comorbidity indices seem to be stronger predictors of complications following hip fracture surgery because comorbidity indices are more likely to be predictive when there are higher complication rates.

There are also a number of limitations associated with the NSQIP database. First, the variables included in the NSQIP database are fairly generic, largely because NSQIP follows such a wide variety of surgical procedures. This creates somewhat of a challenge when investigating a particularly specific condition, such as proximal humerus fracture, because the variables may not all be relevant, or there may be potentially relevant variables that are not included. The preoperative variables and postoperative

Table VI Multivariate analysis of the association of Frailty Index and Charlson Comorbidity Index on any adverse event

Variables	mFI-5			mCCI		
	Odds ratio	95% CI	*P* value	Odds ratio	95% CI	*P* value
Age	1.006	1.004-1.007	<.001	1.006	1.005-1.007	<.001
BMI	0.996	0.994-0.998	<.001	0.996	0.994-0.998	<.001
Procedure: ORIF	0.937	0.897-0.978	.003	0.937	0.897-0.979	.004
Procedure: TSA	0.937	0.893-0.983	.008	0.937	0.893-0.984	.009
mFI-5	1.039	1.019-1.058	<.001	—	—	—
mCCI	—	—	—	1.032	1.016-1.047	<.001
ASA class	1.154	1.126-1.183	<.001	1.157	1.130-1.185	<.001

BMI, body mass index; *ORIF*, open reduction and internal fixation; *TSA*, total shoulder arthroplasty; *mFI-5*, 5-factor modified Frailty Index; *mCCI*, modified Charlson Comorbidity Index; *ASA*, American Society of Anesthesiologists; *CI*, confidence interval.

Table VII Multivariate analysis of the association of Frailty Index and Charlson Comorbidity Index on minor complications

Variables	mFI-5			mCCI		
	Odds ratio	95% CI	*P* value	Odds ratio	95% CI	*P* value
Age	1.007	1.005-1.008	<.001	1.007	1.005-1.009	<.001
BMI	0.994	0.992-0.996	<.001	0.995	0.991-0.998	.003
Procedure: ORIF	0.912	0.863-0.964	.001	0.890	0.826-0.960	.002
Procedure: TSA	0.937	0.882-0.995	.035	0.994	0.900-1.098	.905
mFI-5	1.049	1.025-1.074	<.001	—	—	—
mCCI	—	—	—	1.048	1.017-1.080	.002
ASA class	1.172	1.060-1.296	.002	1.206	1.040-1.398	.013

BMI, body mass index; *ORIF*, open reduction and internal fixation; *TSA*, total shoulder arthroplasty; *mFI-5*, 5-factor modified Frailty Index; *mCCI*, modified Charlson Comorbidity Index; *ASA*, American Society of Anesthesiologists; *CI*, confidence interval.

Table VIII Multivariate analysis of the association of Frailty Index and Charlson Comorbidity Index on major complications

Variables	mFI-5			mCCI		
	Odds ratio	95% CI	*P* value	Odds ratio	95% CI	*P* value
Age	1.002	1.001-1.104	.002	1.001	1.000-1.003	.11
BMI	0.999	0.994-0.998	.19	0.999	0.997-1.002	.64
Procedure: ORIF	0.993	0.897-0.978	.70	0.988	0.939-1.039	.64
Procedure: TSA	0.988	0.893-0.983	.568	1.009	0.943-1.079	.80
mFI-5	1.020	1.019-1.058	.021	—	—	—
mCCI	—	—	—	1.033	1.012-1.054	.002
ASA class	1.004	0.936-1.076	.92	0.994	0.899-1.099	.90

BMI, body mass index; *ORIF*, open reduction and internal fixation; *TSA*, total shoulder arthroplasty; *mFI-5*, 5-factor modified Frailty Index; *mCCI*, modified Charlson Comorbidity Index; *ASA*, American Society of Anesthesiologists; *CI*, confidence interval.

complications that were investigated in the present study were limited to those collected by NSQIP. The ability of mFI-5, mCCI, and ASA class to predict more condition- and procedure-specific outcomes, such as postoperative range of motion of the shoulder joint following surgical management of proximal humerus fracture, may be of particular interest for future studies. In addition, follow-up data are limited to 30 days; thus, complications after that period are not included in the NSQIP database. However, there may be a significant proportion of patients who present with complications after 30 days that are not being accounted for. Lastly, the present study is a retrospective analysis, which has its own limitations. Although this study design allows us to work with a large volume of data in an

efficient manner, retrospective studies restrict the variables that we are able to study, and force us to rely on others for accurate data collection, which can result in missing or incomplete data, as was the case in this study.

Given the limitations of the NSQIP database, particularly in relation to orthopedics, alternative and rising orthopedic registries may provide more relevant and granular data while still allowing for large sample data analyses with increased generalizability. The growing use of these data registries for more outcome-based, quality improvement purposes represents a significant movement for the orthopedic community—an opportunity to make meaningful improvements in patient care. Although there are logistic and financial challenges that are associated with the use of orthopedic registries, there are a number of Internet-based registry systems that may alleviate these concerns. For instance, CareSense (Medtrak), KareOutcomes, and Surgical Outcomes System (Arthrex) are a few of these registry systems that facilitate collection of intra- and extra-operative data, and their web-based software allows for efficient patient follow-up and surveying. These systems also enable integration of outcome data reporting into electronic medical records, which reduces logistical burden. National registries sponsored by the American Academy of Orthopaedic Surgeons, such as the American Joints Replacement Registry, also have specific requirements on data collection, which ensures that granular data be collected. Furthermore, use of registries can improve efficiency and lower costs of documentation.

Conclusions

Although the mFI-5 and mCCI are both strongly associated with adverse events and widely used in outcomes research, the results of the present study suggest that these comorbidity indices have moderate discriminative ability for complications following surgical management of proximal humerus fracture, and are inferior to ASA class in that regard. Further research is needed to elucidate other comorbidity indices that may add predictive value in the operative management of proximal humerus fractures, perhaps with the use of more condition- and procedure-specific databases. The development of specific comorbidity indices may help guide treatment strategy and assist in optimizing prophylaxis regimens to minimize postoperative adverse events.

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