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Simplified Frailty Index as a Predictor of Adverse Outcomes in Total Hip and Knee Arthroplasty

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ABSTRACT

Background: The modified frailty index (mFI) has been shown to predict adverse outcomes in multiple nonorthopedic surgical specialties. This study aimed to assess whether mFI is a predictor of adverse events in patients undergoing primary total hip arthroplasty (THA) and total knee arthroplasty (TKA).
Methods: Patients who underwent THA and TKA from 2005-2012 were identified in the National Surgical Quality Improvement Program database. mFI was calculated for each patient using 15 variables found in National Surgical Quality Improvement Program. Bivariate and multivariate analyses of postoperative adverse events, including Clavien-Dindo grade IV complications, were performed.
Results: A total of 14,583 THA and 25,223 TKA patients were included for analysis. The mean (standard deviation, range) mFIs were 0.083 (0.080, 0-0.55) for THA and 0.097 (0.080, 0-0.64) for TKA cohorts. On bivariate analyses, incidence of Clavien-Dindo grade IV complications (cardiac arrest, myocardial infarction, septic shock, pulmonary embolism, postoperative dialysis, reintubation, and prolonged ventilator requirement), hospital-acquired conditions (surgical site infection, venous thromboembolism, and urinary tract infection), any complications, and mortality increased significantly with increase in mFI ($P < .0001$ for all). Adjusting for demographics, age $\geq$ 75, body mass index $\geq$40, American Society of Anesthesiologists class $\geq$4, and nonclean wound status, mFI $\geq$0.45 was shown to be the strongest independent predictor of Clavien-Dindo grade IV complications for both THA and TKA cohorts with odds ratios of 5.140 and 4.183, respectively.
Conclusion: mFI $\geq$0.45 is an independent predictor of Clavien-Dindo grade IV complications in TKA/THA patients with greater odds ratios than age >75, body mass index $\geq$40, American Society of Anesthesiologists class $\geq$4. mFI should be considered for risk stratifying joint arthroplasty patients preoperatively and perhaps determining immediate postoperative destination.

The demand for total hip arthroplasty (THA) and total knee arthroplasty (TKA) in the United States is increasing. A recent study predicted the demand for THA to increase by 174% to 572,000 procedures annually and TKA to increase by 673% to 3.48 million procedures per year by 2030 [1]. This is partially driven by an aging American population with the number of Americans over 65 expected to double to 88 million from 2014 to 2050 [2]. Although THA and TKA are considered relatively routine and safe interventions [3-5], the projected increase in demand, aging population, and growing emphasis from payers on cost-containment programs such as Medicare's mandatory Comprehensive Care for Joint Replacement bundle, all warrant better risk stratification for improved patient outcomes and more efficient utilization of health care resources.

Although patients generally accumulate physiologic and functional deficits with age [6], the rate at which this happens is influenced by factors such as genetic predisposition, socioeconomic background, and health literacy. The concept of frailty, defined as a decrease in physiologic reserves and multisystem impairments separate from the normal process of aging, has been shown to be more effective in assessing risk in patients undergoing surgery than age alone. A variety of methods for measuring the degree of

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frailty have been proposed, however, the frailty index (FI)—first introduced by the Canadian Study of Health and Aging (CSHA)—provides a standardized framework utilizing easily measurable and objective parameters from regular patient encounters [7]. Since its introduction, CSHA-FI has been shown to be an accurate predictor of survival in older individuals [8,9], and the modified frailty index (mFI), which was constructed from a subset of variables available in the original CSHA-FI, has proven to be effective in predicting adverse postoperative outcomes in multiple surgical specialties [10-12].

To our knowledge, mFI has not yet been studied in the realm of orthopedics. Considering the generalizability of the mFI demonstrated thus far in other surgical fields, we sought to investigate the applicability of the mFI for joint arthroplasty surgeries. We hypothesized that mFI would be a predictor of adverse postoperative events in patients undergoing primary THA and TKA.

Materials and Methods

Data Source

The American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database was queried under the NSQIP data use agreement. The NSQIP was launched in 1994 as a health care quality improvement initiative within the Veteran's Administration health system [13]. Successful implementation at the Veteran's Administration prompted the inception of a parallel program for private hospitals in 1999 [14]. Currently, the NSQIP collects over 150 patient variables from medical reports, operative reports, and patient interviews to record 30-day postoperative morbidity, mortality, and other outcomes. The 2012 NSQIP database, which was the most recent database included in the study, included approximately 550,000 cases collected from over 350 sites [15]. Trained on-site surgical clinical reviewers stringently maintain the quality of the database, and the NSQIP routinely conducts internal auditing to ensure accuracy of data collection and to control interrater reliability [15].

Study Population

The NSQIP databases from 2005 to 2012 were queried. Patients aged 18 years or older who underwent primary THA or TKA were identified using the Current Procedural Terminology codes 21,730 and 27,447, respectively.

Patient Variables

Demographics (age, gender, and race), body mass index (BMI), American Society of Anesthesiologist (ASA) class, wound class, and preoperative wound class were the patient characteristics examined.

The mFI scoring system used in the present study was devised by Saxton and Velanovich by matching 11 variables in the original CSHA-FI to 15 variables available in the NSQIP database [16]. The exact scheme of mapping is presented in Table 1. One point is assigned to the history or current condition of, congestive heart failure, myocardial infarction (MI), previous percutaneous coronary intervention of angina, hypertension requiring medication, transient ischemic attack or cerebrovascular accident without neurological deficit, cerebrovascular accident with neurological deficit, peripheral vascular disease or ischemic rest pain, chronic obstructive pulmonary disease (COPD) or current pneumonia, diabetes mellitus, nonindependent functional status, and impaired sensorium. Nonindependent functional status, per the NSQIP, is defined as requiring some or all assistance from another person for activities of daily living, which includes bathing, feeding, dressing, toileting, mobility, and more. Total points for each patient is divided by 11, which is the total available points, to yield the mFI score for the patient. The range of the mFI is from 0.0 to 1.0 with increments of 0.09, and increasing mFI implies increasing frailty [10-12].

Table 1
Items of CSHA-FI Mapped onto the NSQIP Comorbidity Variables.

CSHA-FI	NSQIP
Congestive heart failure	History of congestive heart failure
Myocardial infarction	History of myocardial infarction
Cardiac problems	History of percutaneous coronary intervention or angina
Arterial hypertension	History of hypertension requiring medication
Cerebrovascular problems	History of transient ischemic attack or cerebrovascular accident without neurological deficit
History of stroke	History of cerebrovascular accident with neurological deficit
Decreased peripheral pulses	History of peripharal vascular disease or ischemic rest pain
Respiratory problems	History of chronic obstructive pulmonary disease or current pneumonia
History of diabetes mellitus	History of diabetes mellitus
Changes in everyday activity, problems getting dressed, problems with bathing, problems with carrying out personal grooming, problems cooking, problems going out alone	Nonindependent functional status
Clouding or delirium	History of impaired sensorium

CSHA-FI, Canadian Study of Health and Aging-Frailty Index, NSQIP, National Surgical Quality Improvement Program.

Wound class, per the NSQIP, is defined as follows: class I (clean) wound denoted no infection or inflammation; no entry to the respiratory, alimentary, genital, or urinary tract and the wound that is primarily closed; class II (clean/contaminated) wound is classified as entry into the respiratory, alimentary, genital, or urinary tract under controlled conditions without unusual contaminations; class III (contaminated) wound included cases with major break in sterile technique; spillage from the gastrointestinal tract and open, fresh, and accidental wounds; class IV (dirty/infected) wound denoted existing clinical infection, perforated viscera, or retained devitalized tissue [15].

Outcome Measures

Clavien-Dindo classification system for surgical complications was used in the study due to its objectivity and reproducibility as previously demonstrated [17]. Primary outcomes assessed in this study were Clavien-Dindo grade IV, hospital-acquired conditions, any complications, and mortality. A Clavien-Dindo grade IV complication encompasses life-threatening conditions involving single or multiorgan dysfunction requiring intermediate care or intensive care unit (ICU) management [18,19]. It includes cardiac arrest, MI, septic shock, pulmonary embolism, postoperative dialysis, need for reintubation, and prolonged ventilator requirements, which can be identified in the NSQIP. Hospital-acquired condition includes surgical site infection, urinary tract infection, and venous thromboembolism. Any complication variable was defined as all tracked postoperative complications in the NSQIP database with the exception of blood transfusion because the database does not differentiate between intraoperative and postoperative transfusion.

Data Analysis

Statistical analyses were performed using the SAS software (version 9.3, SAS Institute Inc, Cary, NC). For univariate analyses, Student *t* test was used for continuous variables while Chi-square test was used for categorical variables. Multivariate logistic regression analyses were performed to assess whether the mFI was a significant predictor of the Clavien-Dindo grade IV complications while controlling for demographic variables and other variables in the NSQIP known to be associated with adverse surgical outcomes such as, BMI, ASA class, and wound class [10-12,20-22]. Because only 12 patients (0.03%) had an mFI ≥0.54, patients with mFI ≥0.45, which is equivalent to having 5 or more conditions in the mFI scoring system, were grouped as a single group to avoid statistical inaccuracy. Statistical significance level was maintained at 0.05.

Results

There were 14,583 and 25,223 patients who received THA and TKA, respectively, in the NSQIP database from 2005 to 2012; 55.6% of the THA group and 63.5% of the TKA group were female. Mean age was 65.2 and 67.1 for the THA and TKA cohorts, respectively. A greater proportion of TKA patients were found in higher obesity classes when compared to patients undergoing THA (Table 2). Mean (standard deviation [SD], range) mFIs were 0.083 (0.080, 0-0.55) for THA group and 0.097 (0.080, 0-0.64) for TKA group. The modes of mFIs were 0.09 for both groups, as shown in Figure 1.

All outcome variables assessed in the study increased stepwise with increasing mFI except for 30-day mortality in the TKA group, where mortality was 0% in the group with mFI ≥0.45. Although the mortality rate remained high at 4.17% for patients with mFI ≥0.45 that underwent THA, the mortality rate results for patients with mFI ≥0.45 is not likely to be reliable given low overall mortality rates (0.29% for THA and 0.15% for TKA) and small number of patients with mFI ≥0.45. As mFI increased from 0 to ≥0.45, Clavien-Dindo grade IV complication rates increased from 0.67% to 12.5% and 1.14% to 8.51% for THA and TKA groups, respectively. The rate of any complication increased from 2.78% to 20.83% as mFI increased from 0 to ≥0.45 in the THA group, whereas the rate increased from 4.06% to 21.28% in the TKA group (Tables 3 and 4).

Adjusting for age ≥75, obesity class III (BMI ≥40), ASA class≥4, and nonclean wound class, mFI ≥0.45 was shown to be the strongest independent predictor of Clavien-Dindo grade IV complications for both the THA and TKA cohorts odds ratios (OR) of 5.140 (95% confidence interval = 1.400-18.871) and 4.183 (95% confidence interval = 1.464-11.948), respectively. Other significant predictors of Clavien-Dindo grade IV complications in patients undergoing THA were age ≥75 and ASA class ≥4, while female gender was found to be protective. Similar results were seen in patients undergoing TKA, where obesity class was also found to be a predictor of Clavien-Dindo grade IV complications (Table 5).

Table 2
Demographics of Patients Undergoing THA and TKA.

Demographics	THA	TKA
N	14,584	25,223
Average age, y	65.2	67.1
Age		
18-39	2.6%	0.5%
40-64	44.3%	39.2%
65-74	29.0%	35.0%
≥75	24.1%	25.3%
Gender		
Female	55.6%	63.5%
Male	44.4%	36.5%
Race		
White	72.7%	71.0%
Black	6.1%	6.3%
Hispanic	3.1%	6.1%
Asians	0.8%	1.4%
Other	0.3%	0.4%
Unknown	17.1%	14.7%
BMI group		
Nonobese (BMI 18.5-29.9)	56.5%	38.9%
Obese I (BMI 30-34.9)	24.5%	28.2%
Obese II (BMI 35-39.9)	11.8%	18.0%
Obese III (BMI ≥40)	7.2%	14.9%
ASA class		
1-No disturb	4.4%	2.2%
2-Mild disturb	53.0%	49.6%
3-Severe disturb	40.6%	46.5%
4-Life threat	2.0%	1.6%
5-Moribund	0.0%	0.0%
Wound class		
1-Clean	97.8%	98.4%
2-Clean/contaminated	1.4%	1.3%
3-Contaminated	0.7%	0.2%
4-Dirty/infected	0.1%	0.1%

THA, total hip arthroplasty, TKA, total knee arthroplasty, BMI, body mass index, ASA, American Society of Anesthesiologists.

Discussion

In the setting of increasing demands for joint arthroplasty surgeries and the aging population in the United States, efficient risk stratification in elderly patients will be critical for better surgical outcomes and health care resource utilization. FI, consisting of 70 measurable variables that mFI is based on, has been proposed by CSHA to identify “frail” patients with decreased physiologic reserve who were more “accident-prone.” The CSHA-FI has proven to be successful in risk assessment and predicting decline in health and mortality in elderly [8,9,23-25]. A recent study showed that any combination of 10 variables available in the CSHA-FI yields similar predictive value compared to the use of all 70 variables [26]. Saxton and Velanovich [16] constructed mFI using 11 variables from CSHA-FI that can be matched to 15 variables available in the NSQIP, and the validity of mFI has been shown in the realms of colectomy [11], vascular surgery [10], and otolaryngology surgeries [12] using the NSQIP database.

In conjunction with mFI, we chose Clavien-Dindo grade IV complications as the primary outcome of interest because it has been shown to be objective and highly reproducible across different specialties [17]. More importantly, Clavien-Dindo grade IV complications include those that are life threatening and require intermediate care or ICU management, which occur in approximately 0.6%-3.3% of patients undergoing joint arthroplasty surgeries [27,28]. Predicting complications that might result in ICU admission may improve hospitalization outcomes and reduce health care costs because unplanned ICU admissions have been shown to be associated with high patient mortality rate [29] and higher costs, accounting for approximately 1 of every 3 dollars spent on health care [30]. Of note, the rate of unplanned ICU admission among all ICU admissions in patients that underwent joint arthroplasty surgeries is reported to be 20% [31,32]. Unfortunately, as NSQIP lacks information about ICU admissions, definitive statements could not be made on the association between mFI and ICU admission.

The overall complication rates were 4.68% in THA group and 5.16% in TKA group. This was in line with the results of the previous studies reporting low rates of major adverse events (1.7~5.6%) after joint arthroplasties [33-35] and corroborates that THA and TKA are relatively routine and safe procedures [3-5]. The mean mFI scores were 0.083 and 0.097 for patients undergoing THA and TKA, respectively, which corresponds to having approximately 1

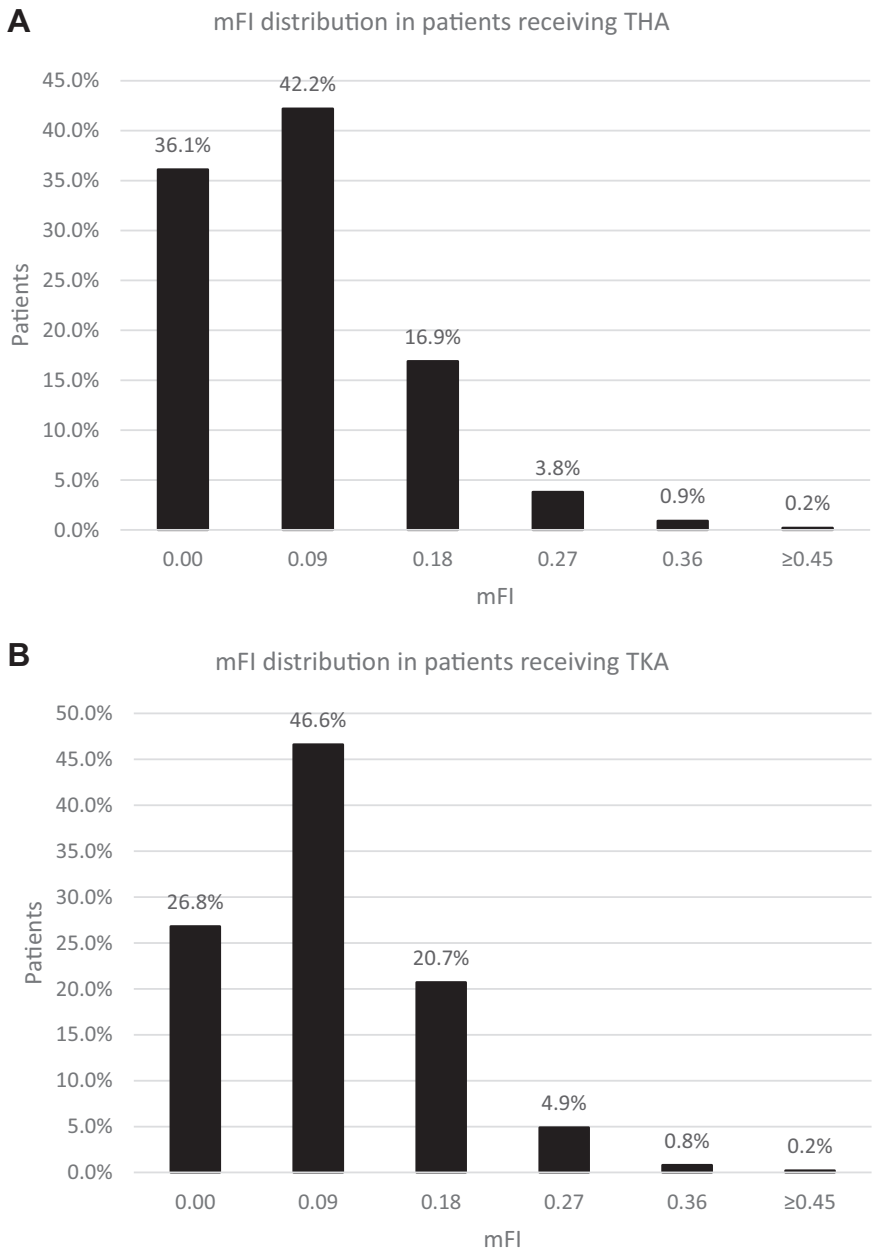

Fig. 1. (A) mFI distribution in patients undergoing total hip arthroplasty (THA). Mean (SD) = 0.083 (0.080). (B) mFI distribution in patients undergoing total knee arthroplasty (TKA). Mean (SD) = 0.097 (0.080). mFI, modified frailty index; SD, standard deviation.

Table 3
Postoperative Outcomes in Patients Undergoing THA by Modified Frailty Index.

Outcomes	All	Modified Frailty Index						*P* Value
		0	0.09	0.18	0.27	0.36	≥0.45	
Any complication, %	4.68	2.78	4.56	6.87	11.09	15.67	20.83	<.0001
Clavien IV complications, %	1.25	0.67	1.09	1.91	4.55	3.73	12.50	<.0001
Hospital-acquired conditions, %[a]	3.42	2.23	3.46	4.88	6.36	8.21	12.50	<.0001
Mortality, %	0.29	0.08	0.28	0.45	1.09	2.24	4.17	<.0001

THA, total hip arthroplasty.
[a] Hospital-acquired conditions consist of surgical site infection, wound dehiscence, urinary tract infection, and venous thromboembolism.

Table 4
Postoperative Outcomes in Patients Undergoing TKA by Modified Frailty Index.

Outcomes	All	Modified Frailty Index						*P* Value
		0	0.09	0.18	0.27	0.36	≥0.45	
Any complication, %	5.16	4.06	5.02	5.56	8.77	14.15	21.28	<.0001
Clavien IV complications, %	1.61	1.14	1.43	1.86	3.82	5.85	8.51	<.0001
Hospital-acquired conditions, %[a]	4.20	3.57	4.23	4.29	5.77	9.76	12.77	<.0001
Mortality, %	0.15	0.07	0.13	0.21	0.32	1.95	0.00	<.0001

TKA, total knee arthroplasty.
[a] Hospital-acquired conditions consist of surgical site infection, wound dehiscence, urinary tract infection, and venous thromboembolism.

Table 5
Predictors of Clavien-Dindo grade IV complications.

Variable	THA				TKA			
	OR	95% CI		*P* Value	OR	95% CI		*P* Value
mFI ≥0.45	5.140	1.400	18.871	.0136	4.183	1.464	11.948	.0075
Age ≥75	1.791	1.296	2.476	.0004	1.947	1.572	2.411	<.0001
Female	0.694	0.516	0.932	.0151	0.761	0.622	0.930	.0077
Obesity class III	1.467	0.878	2.454	.1438	1.435	1.096	1.879	.0086
ASA class ≥4	3.376	1.913	5.957	<.0001	1.938	1.134	3.312	.0155
Nonclean wound class	1.839	0.887	3.810	.1014	0.605	0.224	1.631	.3205

THA, total hip arthroplasty, TKA, total knee arthroplasty, OR, odds ratio, CI, confidence interval, mFI, modified frailty index, ASA, American Society of Anesthesiologists.

condition of 11 listed in the mFI. This is slightly higher than the mean (SD) mFI of 0.07 (0.09) in patients receiving head and neck surgeries and comparable to the mean (SD) mFI of 0.10 (0.11) in patients undergoing colectomy. In patients undergoing colectomy or head and neck surgery, mFI was found to be a strong predictor for Clavien-Dindo grade IV complications or mortality [11,12], and in patients receiving vascular surgery, mFI was identified as a predictor for mortality [10]. mFI was also found to be a predictor of Clavien-Dindo grade IV complications with higher ORs than other variables including advanced age, obesity class III, and ASA class 4 in patients undergoing joint arthroplasties. Unlike other authors, we did not perform the multivariate regression analysis on mortality because the overall mortality rates were low (0.29% for THA group and 0.15% for TKA group). Thus far, it seems that mFI as a predictor of Clavien-Dindo grade IV complications has broad generalizability in different surgical specialties given the results we present and the findings from other studies.

Although the present study is the first to assess FI in predicting adverse postoperative outcomes in arthroplasty patients, there have been other tools that have been developed to serve a similar function. Wuerz et al [35] devised morbidity and mortality acute predictor named arthro-MAP to predict postoperative complications. The components of arthro-MAP include lowest intraoperative heart rate, estimated blood loss, preoperative blood urea nitrogen, procedure type, race, ASA class, comorbidities, and presence of fracture. The study was done at a tertiary care center with 3511 patients, and arthro-MAP is currently undergoing external validation. Courtney et al [36] recently developed Penn Arthroplasty Risk Score (PARS) to predict whether the patient needs postoperative ICU care. PARS is a 7-point scale, with 1 point assigned to COPD, congestive heart failure, coronary artery disease and 2 points assigned to estimated blood loss >1000 mL and the use of intraoperative vasopressor. The authors proposed using the cutoff point of 3 or higher for triage to the ICU postoperatively. However, PARS has not been validated externally to our knowledge.

Comparing the predictive strengths of the mFI to the other tools as a predictor of adverse outcome is out of scope of this study and not feasible because the NSQIP database lacks variables used by other tools. However, there are immediate advantages that mFI presents. The information needed to calculate the mFI can be readily obtained simply by obtaining a thorough history. Component variables in the mFI are objective and do not rely on relatively more subjective scoring such as ASA class. Total mFI score can be obtained preoperatively without the need of intraoperative variables, making it possible to optimize frail patients preoperatively and appropriately plan perioperative care such as prophylactic placement in “ICU Step-Down” monitored settings when appropriate. Finally, being able to use the large national database such as the NSQIP to assess the mFI indirectly confers an advantage due to the larger sample size. Both the arthro-MAP and PARS were derived from single center studies with less than 4000 and 2000 patients, respectively, while the current study involves approximately 40,000 patients. This enables more reliable detection of complications that occur with low frequencies such as Clavien-Dindo grade IV complications, which were seen in 1.25% of patients undergoing THA and 1.61% in patients undergoing TKA.

The data set used in this study, due to its retrospective nature, was allowed establishing associations between the variables studied—we were unable to establish causality. Prospective studies should be performed to validate the strength of the mFI in predicting adverse surgical outcomes and being used as a screening tool for preoperative patient selection and immediate postoperative patient destination (regular floor vs more intense monitoring). This study also suffers from other limitations inherent in database studies. Current Procedural Terminology codes, which were used to identify our study population, were not specific enough to distinguish between minimally invasive procedures and the more traditional surgical approaches. Moreover, data regarding preoperative decision-making were not available. The postoperative data available in the database are limited to 30 days postoperatively, and thus, long-term complications could not be captured. Finally, there were no variables that report functional outcomes, which is often of great interest within orthopedics.

Despite these limitations, the present study is the first to demonstrate the predictive value of mFI in patients undergoing primary THA or TKA. mFI was shown to be a strong predictor of Clavien-Dindo grade IV complications with higher ORs than ASA class, advanced age, and obesity class III. As the index is still in the early phase of being investigated, the mFI is not available online such as the NSQIP risk predictor. The applicability of mFI might be limited to preoperative assessment of ill patients that are already likely to cause concern to physicians (history of MI, percutaneous coronary intervention, stroke, or COPD) and should be useful in preoperative shared decision-making. Precisely determining the subgroup of patients for whom the mFI should be calculated is out of scope of the present study and should be further investigated. Finally, future research demonstrating the validity of mFI in a prospective setting as well as interobserver and intraobserver reliability will be important in further defining the exact role of this index in actual clinical settings.

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