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Predicting Major Adverse Cardiac Events in Spine Fusion Patients

Is the Revised Cardiac Risk Index Sufficient?

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Study Design. Observational cohort study.

Objective. To determine the accuracy of the Revised Cardiac Risk Index (RCRI) in predicting major adverse cardiac events in patients undergoing spine fusion surgery of 3 levels or more.

Summary of Background Data. Preoperative cardiac testing is extensively guided by the RCRI, which was developed and validated in thoracic, abdominal, and orthopedic surgical patients. Because multilevel spine fusion surgery is often associated with major transfusion, we hypothesize that the RCRI may not accurately characterize the risk of cardiovascular morbidity in these patients.

Methods. After institutional review board approval, perioperative data were collected from 547 patients who underwent 3 or more levels of spinal fusion with instrumentation. Postoperative cardiac morbidity was defined as any combination of the following: arrhythmia requiring medical treatment, myocardial infarction (either by electrocardiographic changes or troponin elevation), or the occurrence of demand ischemia. The surgical complexity was categorized as anterior surgery only, posterior cervical and/or thoracic fusion, posterior lumbar fusion, or any surgery that included transpedicular osteotomies. Logistic regression analysis was performed to determine RCRI performance.

Results. The RCRI performed no better than chance (area under the curve = 0.54) in identifying the 49 patients (9%) who experienced cardiac morbidity.

Conclusion. The RCRI did not predict cardiac morbidity in our patients undergoing major spine fusion surgery, despite being extensively validated in low-risk noncardiac surgical patients. Preoperative testing and optimization decisions, previously based on the RCRI, may need to be revised to include more frequent functional cardiac imaging and more aggressive implementation of pharmacologic modalities that may mitigate cardiac morbidity, similar to the preoperative evaluation for major vascular surgery.

Key words: preoperative cardiac risk assessment, preoperative cardiac testing, perioperative cardiac morbidity, perioperative mortality, preoperative assessment, preoperative risk, spine fusion, spine surgery, cardiac events, acute myocardial ischemia, acute myocardial infarction.

Level of Evidence: 3

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Multilevel spine fusion surgery for the treatment of adult spinal disease is often associated with major blood loss, fluid shifts, and transfusion, all of which can cause significant cardiovascular stress with subsequent cardiac morbidity.[1–3] The incidence of major adverse cardiac events (MACE) in spine fusion patients is not clearly delineated in the literature; however, recent studies show that major surgical hemorrhage is an independent predictor of postoperative cardiovascular complications.[4] Presumed risk factors for major morbidity include advanced age, operative duration, surgical complexity, and pre-existing medical comorbidities. Unfortunately, there are no reports specifically documenting the incidence and predisposing risk factors for MACE in major spine fusion surgery, precluding appropriate optimization of patients' cardiovascular comorbidities prior to surgery.[5]

The Revised Cardiac Risk Index (RCRI) is the primary tool of the American Heart Association and the American College of Cardiology guidelines for preoperative risk stratification and cardiac assessment before noncardiac surgery.[6,7] Six factors were found to be independent predictors of cardiac morbidity: history of ischemic heart disease, congestive heart failure, cerebrovascular disease, insulin-dependent

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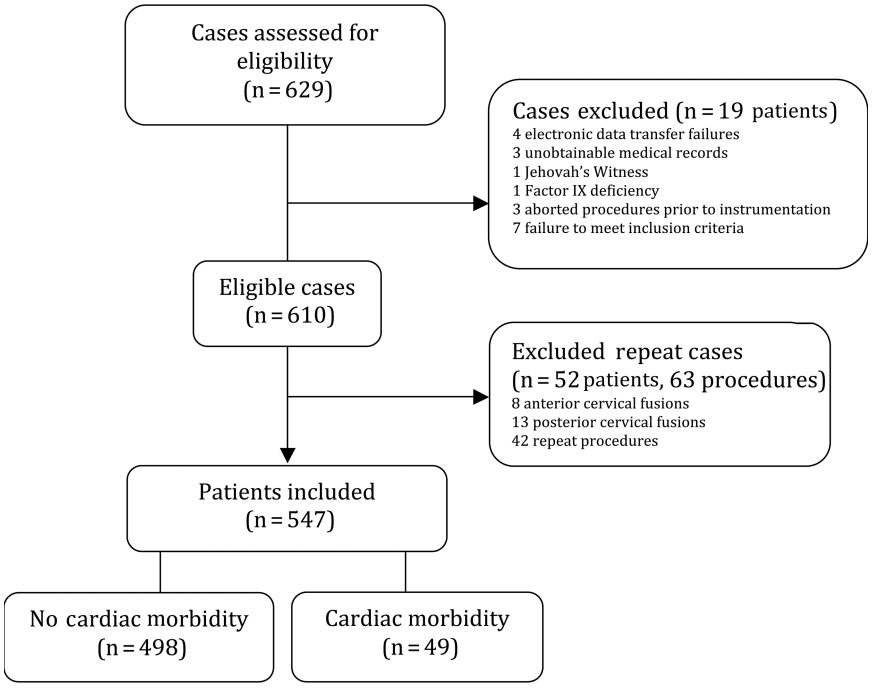

Figure 1. The flow diagram for patient enrollment, inclusion/exclusion, dropout, and final data analysis for patients with and without perioperative cardiac morbidity. To include only 1 surgical procedure for each patient who may have undergone multiple eligible spine surgical procedures throughout the 6-year study period, sequential dropout rules were determined to include the surgical procedure that most closely resembled those of the other patients in the database—posterior spine instrumentation procedures that included the lumbar spine. This was done using *a priori* sequential dropout rules created to preferentially include the surgical procedure that most closely resembled the majority of the patients in the data set—posterior lumbar spine fusion. Therefore, anterior operations were excluded first, posterior cervical operations were excluded next, and if multiple operations remained, the earliest eligible surgical procedure was included.

diabetes mellitus, renal insufficiency (creatinine >2.0 mg/dL), and high-risk surgery.[7] Although the RCRI was developed and validated in a large, single-center cohort of thoracic, abdominal, and orthopedic surgical patients, recent studies have shown the RCRI to significantly underestimate the risk of MACE for patients undergoing major thoracic and vascular surgery such that separate predictive indices are now recommended for preoperative optimization and risk stratification of these patient populations.[6,8–11] In fact, because the risk for MACE in vascular surgery patients exceeds 5% regardless of the patient's medical comorbidities, the American Heart Association/American College of Cardiology guidelines suggest that patients may undergo more stringent cardiovascular testing, independent of the RCRI.[6,8] Subsequent reviews and meta-analyses have found that surgical and intraoperative factors, such as major blood loss, anticipated duration for more than 3 hours, and transfusion of packed red blood cells, may be more influential on the risk of MACE than what is predicted by the RCRI.[4,10,12]

Multilevel spine fusion surgery is currently classified by the RCRI as "low risk" and, therefore, thought to have a 0.4% to 6.6% incidence of MACE, depending on the patient's preoperative comorbidities.[6] The original cohort of patients in the RCRI included orthopedic operations as only 35% of the total, with a relatively few number of complex spine fusion surgical procedures. Because multilevel spinal instrumentation and osteotomies are associated with cardiopulmonary stress from major transfusion, fluid shifts, and surgical stimulation, similar to aortic surgery, we hypothesized that the RCRI would not reflect the risk of MACE in these patients. Furthermore, patients with severe kyphoscoliosis and resultant pain and instability are rarely able to achieve functional status that would preclude the need for an ischemic evaluation. The primary aim of this study was to determine the accuracy of the RCRI in predicting MACE in patients undergoing spine fusion surgery of 3 or more bony levels in order to assist with more accurate preoperative risk stratification, clinical optimization, and informed consent.

MATERIALS AND METHODS

The Strengthening the Reporting of Observational studies in Epidemiology guidelines were used to report the results of this observational cohort study that was approved by the local institutional review board.[13] All patients who underwent instrumented fusion of 3 or more levels and/or osteotomies, between January 1, 2003, and May 30, 2009, met inclusion criteria. The *Current Procedural Terminology* codes that were used to determine the eligible surgical procedures were limited to those for arthrodesis of spine deformity (22800, 22802, 22804, 22810, 22812, and 22819), spinal instrumentation (22842, 22843, 22844, 22846, and 22847), and osteotomy of the spine (22208, 22216, and 22226). In addition, only 3 surgeons' cases were included, whose practices were predominantly focused on the surgical correction of adult spinal disease.

Patients were excluded only if their medical records were missing information pertaining to the variables or outcome measures under evaluation. To include only 1 surgical procedure for each patient who may have undergone multiple eligible spine surgical procedures throughout the 6-year study period, sequential dropout rules were determined to include the surgical procedure that most closely resembled those of the other patients in the database—posterior spine instrumentation procedures that included the lumbar spine. Of the initial 629 cases identified as eligible, a total of 547 patients were included in the final analysis after exclusions and dropouts (Figure 1).

MACE was a composite outcome variable defined by the presence of at least one of the following criteria[9,14–16]:

(a) A new arrhythmia requiring treatment with vasoactive medication infusion, cardioversion, pacing, or defibrillation.
(b) ST segment elevation myocardial infarction: By pathognomonic electrocardiographic change(s).
(c) Non-ST elevation myocardial infarction: Troponin I more than 1.5 ng/mL[1] with or without electrocardiographic changes consistent with ischemia or a new echocardiographic wall motion abnormality.[17]
(d) Demand ischemia: Troponin I more than 0.12 ng/mL[1] but 1.5 ng/mL[1] or less.

The surgical complexity was categorized on the basis of the surgical invasiveness as anterior cervical fusion surgery only (0 points), posterior cervical and/or thoracic fusion (1 point), posterior lumbar fusion (2 points), or any surgery that included transpedicular osteotomies (3 points).[18,19]

Statistics

To accurately evaluate the RCRI, we sought to extract data from 50 patients who experienced MACE—10 events for each of the 5 preoperative variables that comprise the RCRI.[20] Given that the incidence of MACE ranges from 6.6% (RCRI = 2) to 11.0% (RCRI ≥3), 455 to 757 patients would be required to find 50 patients who experienced cardiac morbidity.[7] We estimated that 6 to 10 qualifying spine surgical procedures were performed per month at Northwestern Memorial Hospital. Therefore, we examined patients during a 72-month period, from January 1, 2003, through May 31, 2009, in order to attempt to accrue a sufficient number of patients.

Univariate analysis was performed using NCSS 2004 (Number Cruncher Statistical Systems, Inc., Kaysville, Utah) and multiple logistic regression analyses were performed using StatsDirect statistical software (version 2.6.5, StatsDirect, Ltd., Cheshire, United Kingdom).

All of the data were tested for normality using the Shapiro-Wilk *W* test. Normally distributed data were compared using the unpaired *t* test. Non-normally distributed data were compared using the Mann-Whitney *U* test. Categorical data were compared using Fisher exact test or χ^2 test. A 2-sided *P* value of less than 0.05 was considered statistically significant. Factors from the univariate analysis with a *P* value of less than 0.15 were included in subsequent multivariate logistic regression analyses.

Two separate multivariate logistic regression analyses were performed to determine (a) the predictive ability of the RCRI variables when all surgical procedures were classified as low risk (*i.e.*, 0 points); and (b) the predictive ability of the RCRI variable when all surgical procedures were classified as high risk (*i.e.*, 1 point). The comparison of "high risk" *versus* "low risk" characterization of the surgical variable of the RCRI was necessary because in the original description of the RCRI by Lee *et al*,[7] all spinal fusions were designated as "low risk, which may introduce a bias against the original RCRI. An additional multivariate logistic regression was performed to determine whether there were any other preoperative or demographic predictors of MACE not identified by the RCRI. Multivariate logistic regression models were generated using a hierarchical, backward stepwise selection method in which variables with high *P* values were removed from the model 1 at a time and were excluded from the final model if their removal either did not diminish the fit of the model or actually improved it, as determined by the Pearson χ^2 statistic, the likelihood ratio test statistic, the Hosmer-Lemshow statistic, and the correct prediction of both positive and reference responses. Cross-validation with bootstrapping (1000 samples, with replacement) was used to determine the performance of each generated model. The sensitivity and specificity of the logistic model and the empirical area under the receiver operating characteristic curve were calculated from the model-predicted reference, model-predicted positive responses (using the default threshold probability for positive classification of 0.5), and the actual reference and actual positive responses. The area under the receiver operating characteristic curve (area under the curve [AUC]) was compared with that of a "random" predictive model (AUC = 0.5) with a nonparametric approach.[21] Bias-corrected confidence intervals for the odds ratios (ORs) derived from the final fitted logistic model were determined by bootstrapping (1000 samples, with replacement).

RESULTS

Forty-nine patients (9%) experienced MACE in our surgical population (Table 1). Univariate analysis demonstrated that only age, pre-existing hypertension, and the preoperative use of antihypertensive medications directed at the renin-angiotensin pathway (*i.e.*, angiotensin converting enzyme inhibitors or angiotensin II receptor blockers) were different between patients who did and did not experience MACE (Table 2). Neither of the 2 definitions of the risk of the surgical procedure (high or low) produced an RCRI score that was able to predict cardiac complications (Table 3). Multivariate logistic regression models that were forced to include the 5 preoperative variables that compose the RCRI performed poorly in identifying patients who experienced MACE in our surgical population (AUC, 0.54; 95% confidence interval [CI], 0.47–0.61; $P = 0.226$ *vs*. AUC = 0.5), regardless of whether the surgical procedure was classified as a low- or high-risk procedure (Figure 2).

Multivariate logistic regression demonstrated that only the patient's age category (OR, 2.1; 95% CI, 1.5–3.0; $P < 0.001$) and the surgical complexity (OR, 1.9; 95% CI, 1.1–3.1; $P = 0.011$) were independent predictors of MACE (Table 4). Using just these 2 resulted in a moderately good ability to identify patients who would experience MACE after major spine fusion surgery (AUC = 0.74; 95% CI, 0.65–0.80; $P < 0.0001$ *vs*. AUC = 0.5, Figure 2).

DISCUSSION

Although the RCRI has been validated in low-risk non–cardiac surgical patients, it did not accurately predict cardiac morbidity in patients undergoing major spine fusion surgery. None of the preoperative variables that comprise the RCRI were able to individually distinguish between patients with

TABLE 1. Perioperative Cardiac Morbidity*

Cardiac Morbidity	Incidence N (%)	Troponin (ng/mL) Median (Range)
ST elevation myocardial infarction	1 (0.2)	96.2 (none)
Non-ST elevation myocardial infarction	10 (1.8)	3.89 (1.38–13.65)
Demand ischemia	27 (4.9)	0.35 (0.14–1.4)
Any cardiac ischemia	38 (7.0)	…
Arrhythmia	14 (2.6)	…
Any 1 type of cardiac morbidity	46 (8.4)	…
Any 2 types of cardiac morbidities	3 (0.6)	…
All cardiac morbidity	49 (9.0)	…

**Non-ST elevation myocardial infarction: Troponin >1.5 ng/mL with or without electrocardiographic changes consistent with ischemia or a new echocardiographic wall motion abnormality; demand ischemia: troponin >0.12 ng/mL but ≤1.5 ng/mL.*

or without MACE. In addition, neither conservative nor liberal definitions of surgical risk produced an RCRI score that was able to accurately predict cardiac complications better than chance for this patient population. In fact, the incidence of MACE in our patients with RCRI scores of 0 or 1 (*i.e.*, "low-risk" patients) was 8.6% to 8.8%, whether the surgical risk was categorized as low or high. In contrast, the reported incidence of MACE in RCRI categories 0 or 1 is 0.9%. Our definition of MACE is conservative given that lower levels of troponin elevation used in our definition of demand ischemia are associated with a 4- to 15-fold increase in long-term cardiac morbidity and mortality after vascular or orthopedic surgery.[17,22–32] However, even a small increase in postoperative troponin levels (>0.02 ng/mL) is associated with an increase in 30-day *all-cause mortality*.[33] Therefore, the poor predictive performance of the RCRI in our spine fusion surgery patients suggests that these patients might require more stringent preoperative risk assessment than that dictated by the traditional RCRI algorithm, similar to that required of patients undergoing major vascular surgery.[6,8,10] The goal of this more stringent cardiac functional assessment is not necessarily to identify patients who require preoperative coronary revascularization but rather to identify patients who may benefit from intensive coronary artery disease risk factor control (*e.g.*, statin and β-blocker therapy) prior to undergoing elective operations, as well as to accurately guide informed consent for possible perioperative complications, especially in the case of elective surgery.[2,6,8,17,26,34,35]

Lee *et al*[7] originally defined MACE as myocardial infarction, complete heart block, cardiac arrest, or pulmonary edema. Our definition for MACE differed from this in 3 major ways. First, we included any new arrhythmia requiring treatment in the definition of cardiac morbidity because these often indicate myocardial strain or ischemia and have been associated with increased in-hospital morbidity and length of stay.[6,36] Second, we included demand ischemia with troponin I greater than 0.12 ng/mL[1] rather than myocardial infarction alone. Not only are troponin I elevations commonly used as a specific serum biomarker of myocardial injury in models of MACE but a troponin I greater than 0.08 ng/mL[1] has been found to be independently associated with an increase in long-term cardiac morbidity after noncardiac surgery.[8–10,17,22–33,37–39] This is a conservative definition of demand ischemia, given that many studies use an even lower threshold for diagnosing ischemia and infarction with cardiac biomarkers alone.[11,26,38,39] In fact, the universal definition for myocardial infarction in accordance with the European Society of Cardiology/American Heart Association/American College of Cardiology/World Heart Federation 2007 Task Force states that a sudden rise in cardiac-specific troponin levels (troponin I >99th percentile of normal with a variation coefficient of <10%, >0.06) with progressive decline in the levels in the setting of physiologic stress is consistent with significant myocardial necrosis and even infarction.[17,40] This definition is certainly more sensitive for acute myocardial injury than the definition from the original RCRI publication, but it is also independently predictive of long-term mortality.[2,33,40] The RCRI composite outcome for MACE does not include troponin elevations, because it was developed over a decade ago when troponin assays were not readily available.[37,39] Our study is limited by the fact that troponin levels were not routinely measured in the postoperative period, especially in the patients undergoing surgery between 2003 and 2006; however, this would result in underreporting the incidence of MACE, making the results of this study even more striking.

Our third deviation from the RCRI definition of MACE was exclusion of pulmonary edema in this composite outcome, mainly because complex spine fusion surgery is often associated with extreme fluid shifts and major transfusion, which may result in pulmonary edema regardless of adequate cardiac function. Because objective evaluation of cardiac function was not routinely obtained in patients with clinical evidence of pulmonary edema, we could not accurately differentiate between cardiogenic and noncardiogenic pulmonary edema in this retrospective cohort study. Significantly, our definition of MACE is consistent with several recent reviews and meta-analyses for perioperative cardiac morbidity.[10,38]

Presumably patients who do not undergo stress test have a relatively healthier history or functional capacity and would be expected to be at low risk for cardiac morbidity. However, patients with spine disease are also frequently unable to endorse a reliable functional status because of pain and instability. The absence of a cardiac stress test was not an independent predictor of MACE in our patients (OR, 1.1; 95% CI, 0.6–2.1; $P = 0.745$); however, there was a 7% incidence of MACE in patients who did not undergo stress testing within 5 years of surgery. It is important to note that coronary artery disease was not a significant predictor of MACE ($P = 0.3387$). This is not surprising in light of the evidence demonstrating that medical management of

TABLE 2. Univariate Analysis of Preoperative Medical and Surgical Variables and Demographics*

Variable	No Cardiac Complications, n = 498	Cardiac Complications, n = 49	*P*
Male	303 (60.8%)	28 (57.1%)	0.6473
Age, yr			
<60 yr	272 (54.6%)	9 (18.4%)	<0.0001
60–69 yr	139 (27.9%)	21 (42.9%)	
70–79 yr	74 (14.9%)	17 (34.7%)	
≥80 yr	13 (2.6%)	2 (4.1%)	
Weight	78.0 ± 19.4	76.8 ± 17.2	0.6377
BMI	27.7 ± 5.9	27.1 ± 5.3	0.5350
American Society of Anesthesiologists physical status			
I	28 (5.6%)	1 (2.0%)	0.3223
II	236 (47.4%)	19 (38.8%)	
III	223 (44.8%)	27 (55.1%)	
IV	11 (2.2%)	2 (4.1%)	
Ischemic heart disease	51 (10.2%)	7 (14.3%)	0.3387
Heart failure	11 (2.2%)	2 (4.1%)	0.3275
Cerebrovascular disease	12 (2.4%)	3 (6.1%)	0.1429
Preoperative insulin use	27 (5.4%)	2 (4.1%)	0.7643
Preoperative creatinine ≥2.0 mg/dL	59 (11.8%)	5 (10.2%)	0.8214
Hypertension	222 (44.6%)	34 (69.4%)	0.0009
No stress test within 5 yr	269 (54.0%)	21 (42.9%)	0.1354
Diabetes	66 (13.3%)	5 (10.2%)	0.6604
Smoking	174 (34.9%)	19 (38.8%)	0.6391
Sleep apnea	36 (7.2%)	5 (10.2%)	0.3993
Obstructive pulmonary disease	23 (4.6%)	5 (10.2%)	0.0948
β-Blocker use	158 (31.7%)	21 (42.9%)	0.1500
Angiotensin converting enzyme inhibitor use	139 (27.9%)	24 (49.0%)	0.0031
Statin use	133 (26.7%)	17 (34.7%)	0.2421
Surgical category			
0 (anterior surgery only)	12 (2.4%)	0 (0%)	0.0789
1 (posterior cervical and/or thoracic)	86 (17.3%)	6 (12.2%)	
2 (posterior lumbar)	316 (63.5%)	28 (57.1%)	
3 (transpedicular osteotomies)	84 (17.3%)	15 (30.6%)	
Infection	17 (3.4%)	1 (2.0%)	0.7213
Tumor	26 (5.2%)	4 (8.1%)	0.3322

**Revised Cardiac Risk Index variables shaded in light gray. Variables included in the initial multivariate logistic regression model ($P < 0.15$) shaded in dark gray. BMI indicates body mass index.*

patients with known severe coronary artery disease with plaque stabilization therapy (*i.e.*, β-blockers and statins) was as effective as preoperative coronary revascularization in preventing MACE after major abdominal vascular surgery.[2,41] In addition, serum biomarkers associated with ventricular function (such as B-natriuretic peptide), systemic

TABLE 3. Revised Cardiac Risk Index Variables

Variable	No Cardiac Complications, N = 498, N (%)	Cardiac Complications, N = 49 (9.0%), N (%)		*P*	Odds Ratio (95% CI)
History of ischemic heart disease	51 (10.2)	7 (14.3)		0.3387	1.3 (0.5–3.3)
History of heart failure	11 (2.2)	2 (4.1)		0.3275	1.8 (0.4–9.0)
History of cerebrovascular disease	12 (2.4)	3 (6.1)		0.1429	2.5 (0.7–9.5)
Preoperative insulin use	27 (5.4)	2 (4.1)		0.7643	0.7 (0.1–2.9)
Preoperative creatinine ≥2.0 mg/dL	59 (11.8)	5 (10.2)		0.8214	0.8 (0.3–2.2)
All "Low-Risk" Procedures (0 Points)		N (%)	Incidence (%)		
0: 396 (72.4%)	362 (72.7)	34 (69.4)	8.6	0.569	…
1: 125 (22.9%)	114 (22.9)	11 (22.4)	8.8		
2: 24 (4.4%)	20 (4.0)	4 (8.2)	16.7		
≥3: 2 (0.4%)	2 (0.4)	0 (0)	0.0		
All "High-Risk" Procedures (1 Point)		N (%)	Incidence		
0: 0 (0%)	0 (0)	0 (0)	…	0.500	…
1: 396 (72.4%)	362 (72.7)	34 (69.4)	8.6		
2: 125 (22.9%)	114 (22.9)	11 (22.4)	8.8		
≥3: 26 (4.8%)	22 (4.4)	4 (8.2)	15.4		

CI indicates confidence interval.

inflammation related to atherosclerosis (*e.g.*, cholesterol panel, C reactive protein, *etc.*), or endothelial function may also prove to be important screening tools for cardiac risk stratification.[42]

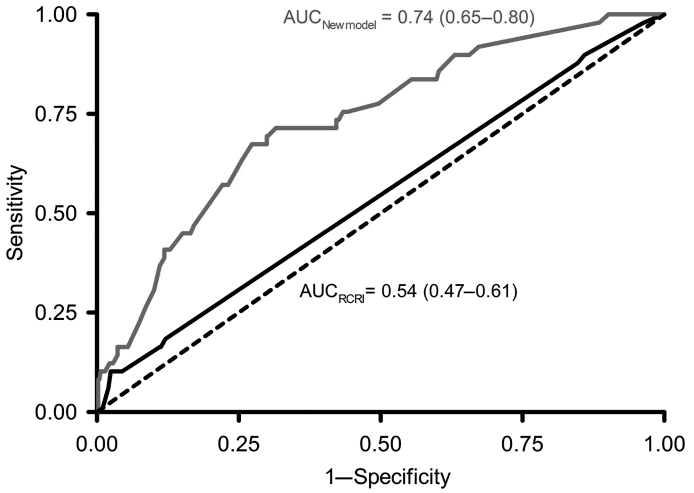

Figure 2. The empiric receiver operating characteristic curves for the Revised Cardiac Risk Index model (solid black line, AUC = 0.54; 95% confidence interval, 0.47–0.61; $P = 0.226$ *vs.* AUC = 0.5) and the predictive ability of the "new model" (solid red line, AUC = 0.74; 95% confidence interval, 0.65–0.80; $P < 0.0001$ *vs.* AUC = 0.5) consisting of age and surgical complexity category. The dotted reference line represents the "line of chance" with AUC = 0.5. AUC indicates area under the curve; RCRI, Revised Cardiac Risk Index.

Limitations

The major limitation of this study is that it is typically associated with a retrospective cohort study from a single center—the accuracy of retrospective clinical data sets commonly comes into question. Fortunately, the data in this analysis originate from common clinical variables used in the routine care of these complex surgical patients.

TABLE 4. Multivariate Logistic Regression Model of Predictors of Cardiac Morbidity*

Variable	Odds Ratio (95% CI)	*P*
Surgical complexity category	1.9 (1.1–3.1)	0.011
Age category	2.1 (1.5–3.0)	<0.001
Cerebrovascular disease	1.9 (0.5–7.8)	0.279
Obstructive pulmonary disease	1.9 (0.6–5.8)	0.113
Hypertension	1.6 (0.7–3.7)	0.098
β-Blocker use	1.0 (0.5–1.9)	0.706
Angiotensin converting enzyme inhibitor use	1.2 (0.6–2.6)	0.134
No stress test within 5 yr	1.1 (0.6–2.1)	0.745

**Logit P = −4.366 + (0.762 × Age) + (0.644 × Surgical category) (AUC = 0.74; 95% CI, 0.65–0.80; P < 0.0001 vs. AUC = 0.5).*
AUC indicates area under the curve; CI, confidence interval.

In addition, these data are most likely to be accurately recorded because they are found in redundant parts of the medical record (*i.e.*, preoperative evaluation by internists, preoperative anesthesia note, anesthetic record, and surgical operative note). Furthermore, we developed clear definitions of preoperative comorbidities and postoperative outcomes that are both consistent with the current literature and objectively obtained through full access to perioperative patient records. Although the single-center nature of this study limits its generalizability, our cohort includes a large population of patients undergoing multilevel spinal instrumentations and complex osteotomies, which were only a minor portion of the single-center data set that was used to derive and validate the RCRI. Because of the complex logistics required to develop purpose-built multicenter databases, starting with that approach could have limited some of the level of detail that was obtained and may have prohibited the identification of important clinical predictors.[43] As discussed previously, troponin levels were not routinely drawn from patients postoperatively until September 2006, which likely presents a bias for underreporting the overall incidence of MACE in our population.[44] The final limitation of this study is that there were a limited number of patients with MACE, thereby limiting the number of variables that could be identified with statistical certainty.[20]

CONCLUSION

Our data demonstrate that patients having complex spine fusion surgery are at high risk for cardiac morbidity, but the RCRI poorly predicts their cardiac risk. Only the complexity of the scheduled operation and the age of the patient were independent predictors of MACE. Therefore, preoperative testing and optimization decisions, currently based on the RCRI, need to be revised for this patient population, which more closely resembles those patients undergoing major vascular surgery. This may include more frequent functional cardiac imaging and more aggressive implementation of pharmacologic modalities to mitigate cardiac morbidity.[6]

➢ Key Points

- ❑ The overall incidence of major cardiac events after 3 or more bony levels of posterior spinal fusion with instrumentation in observational cohort was 49 events in 547 patients (9%).
- ❑ The RCRI was not able to accurately predict MACE after 3 or more bony levels of spinal fusion with instrumentation.
- ❑ Despite evidence in the literature demonstrating a reduction in perioperative MACE with the use of β-blockers and statins, these risk reduction strategies were used in only 42.9% (β-blockers) and 34.7% (statins) of the patients who had cardiac morbidity.

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References

1. Yang BP, Ondra SL, Chen LA, et al. Clinical and radiographic outcomes of thoracic and lumbar pedicle subtraction osteotomy for fixed sagittal imbalance. *J Neurosurg Spine* 2006;5:9–17.
2. Priebe HJ. Perioperative myocardial infarction—aetiology and prevention. *Brit J Anaesth* 2005;95:3–19.
3. Carabini LM, Zeeni C, Moreland NC, et al. Development and validation of a generalizable model for predicting major transfusion during spine fusion surgery. *J Neurosurg Anesthesiol* 2014;26:205–15.
4. Kamel H, Johnston SC, Kirkham JC, et al. Association between major perioperative hemorrhage and stroke or Q-wave myocardial infarction. *Circulation* 2012;126:207–12.
5. Glassman SD, Hamill CL, Bridwell KH, et al. The impact of perioperative complications on clinical outcome in adult deformity surgery. *Spine* 2007;32:2764–70.
6. Fleisher LA, Beckman JA, Brown KA, et al. 2009 ACCF/AHA focused update on perioperative beta blockade incorporated into the ACC/AHA 2007 guidelines on perioperative cardiovascular evaluation and care for noncardiac surgery. *J Am Coll Cardiol* 2009;54:e13–118.
7. Lee TH, Marcantonio ER, Mangione CM, et al. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. *Circulation* 1999;100:1043–9.
8. Bertges DJ, Goodney PP, Zhao Y, et al. The Vascular Study Group of New England Cardiac Risk Index (VSG-CRI) predicts cardiac complications more accurately than the Revised Cardiac Risk Index in vascular surgery patients. *J Vasc Surg* 2010;52:674–83, 683.e1–683.e3.
9. Brunelli A, Varela G, Salati M, et al. Recalibration of the revised cardiac risk index in lung resection candidates. *Ann Thorac Surg* 2010;90:199–203.
10. Ford MK, Beattie WS, Wijeysundera DN. Systematic review: prediction of perioperative cardiac complications and mortality by the revised cardiac risk index. *Ann Intern Med* 2010;152:26–35.
11. Gupta PK, Gupta H, Sundaram A, et al. Development and validation of a risk calculator for prediction of cardiac risk after surgery. *Circulation* 2011;124:381–7.
12. Kheterpal S, O'Reilly M, Englesbe MJ, et al. Preoperative and intraoperative predictors of cardiac adverse events after general, vascular, and urological surgery. *Anesthesiology* 2009;110:58–66.
13. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet* 2007;370:1453–7.
14. Ackland GL, Harris S, Ziabari Y, et al. Revised cardiac risk index and postoperative morbidity after elective orthopaedic surgery: a prospective cohort study. *Brit J Anaesth* 2010;105:744–52.
15. Boersma E, Kertai MD, Schouten O, et al. Perioperative cardiovascular mortality in noncardiac surgery: validation of the Lee cardiac risk index. *Am J Med* 2005;118:1134–41.
16. Fihn SD, Gardin JM, Abrams J, et al. 2012 ACCF/AHA/ACP/AATS/PCNA/SCAI/STS guideline for the diagnosis and management of patients with stable ischemic heart disease: executive summary: a report of the American College of Cardiology Foundation/American Heart Association task force on practice guidelines, and the American College of Physicians, American Association for Thoracic Surgery, Preventive Cardiovascular Nurses Association, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons. *Circulation* 2012;126:3097–137.
17. Feringa HH, Bax JJ, Boersma E, et al. High-dose beta-blockers and tight heart rate control reduce myocardial ischemia and

troponin T release in vascular surgery patients. *Circulation* 2006;114: I344–9.
18. Cizik AM, Lee MJ, Martin BI, et al. Using the spine surgical invasiveness index to identify risk of surgical site Infection: a multivariate analysis. *J Bone Joint Surg Am* 2012;94:335–42.
19. Mirza SK, Deyo RA, Heagerty PJ, et al. Development of an index to characterize the "invasiveness" of spine surgery: validation by comparison to blood loss and operative time. *Spine* 2008;33:2651–61. doi:10.1097/BRS.0b013e31818dad07.
20. Pace NL. Independent predictors from stepwise logistic regression may be nothing more than publishable P values. *Anesth Analg* 2008;107:1775–8.
21. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics* 1988;44:837–45.
22. Ausset S, Auroy Y, Lambert E, et al. Cardiac troponin I release after hip surgery correlates with poor long-term cardiac outcome. *Eur J Anaesthesiol* 2008;25:158–64.
23. Ausset S, Auroy Y, Verret C, et al. Quality of postoperative care after major orthopedic surgery is correlated with both long-term cardiovascular outcome and troponin Ic elevation. *Anesthesiology* 2010;113:529–40.
24. Ausset S, Minville V, Marquis C, et al. Elevated serum cardiac troponin I in older patients with hip fracture: incidence and prognostic significance. *Arch Orthop Trauma Surg* 2008;128:761–2.
25. Barbagallo M, Casati A, Spadini E, et al. Early increases in cardiac troponin levels after major vascular surgery is associated with an increased frequency of delayed cardiac complications. *J Clin Anesth* 2006;18:280–5.
26. Feringa HH, Schouten O, Karagiannis SE, et al. Intensity of statin therapy in relation to myocardial ischemia, troponin T release, and clinical cardiac outcome in patients undergoing major vascular surgery. *J Am Coll Cardiol* 2007;50:1649–56.
27. Fisher AA, Southcott EN, Goh SL, et al. Elevated serum cardiac troponin I in older patients with hip fracture: incidence and prognostic significance. *Arch Orthop Trauma Surg* 2008;128:1073–9.
28. Kertai MD, Boersma E, Klein J, et al. Long-term prognostic value of asymptomatic cardiac troponin T elevations in patients after major vascular surgery. *Eur J Vasc Endovasc* 2004;28:59–66.
29. Landesberg G, Mosseri M, Shatz V, et al. Cardiac troponin after major vascular surgery: the role of perioperative ischemia, preoperative thallium scanning, and coronary revascularization. *J Am Coll Cardiol* 2004;44:569–75.
30. Landesberg G, Shatz V, Akopnik I, et al. Association of cardiac troponin, CK-MB, and postoperative myocardial ischemia with long-term survival after major vascular surgery. *J Am Coll Cardiol* 2003;42:1547–54.
31. Lopez-Jimenez F, Goldman L, Sacks DB, et al. Prognostic value of cardiac troponin T after noncardiac surgery: 6-month follow-up data. *J Am Coll Cardiol* 1997;29:1241–5.
32. Oscarsson A, Eintrei C, Anskar S, et al. Troponin T-values provide long-term prognosis in elderly patients undergoing non-cardiac surgery. *Acta Anaesth Scand* 2004;48:1071–9.
33. Devereaux PJ, Chan MT, Alonso-Coello P, et al. Association between postoperative troponin levels and 30-day mortality among patients undergoing noncardiac surgery. *JAMA* 2012;307: 2295–304.
34. Devereaux PJ, Yang H, Yusuf S, et al. Effects of extended-release metoprolol succinate in patients undergoing non-cardiac surgery (POISE trial): a randomised controlled trial. *Lancet* 2008;371: 1839–47.
35. Afilalo J, Flynn AW, Shimony A, et al. Incremental value of the preoperative echocardiogram to predict mortality and major morbidity in coronary artery bypass surgery. *Circulation* 2013;127: 356–64.
36. Rostagno C, La Meir M, Gelsomino S, et al. Atrial fibrillation after cardiac surgery: incidence, risk factors, and economic burden. *J Cardiothorac Vasc Anesth* 2010;24:952–8.
37. Keller T, Ojeda F, Zeller T, et al. Defining a reference population to determine the 99th percentile of a contemporary sensitive cardiac troponin I assay. *Int J Cardiol* 2013;167:1423–9. doi:10.1016/j.ijcard.2012.04.063.
38. Le Manach Y, Perel A, Coriat P, et al. Early and delayed myocardial infarction after abdominal aortic surgery. *Anesthesiology* 2005;102:885–91.
39. Luepker RV, Apple FS, Christenson RH, et al. Case definitions for acute coronary heart disease in epidemiology and clinical research studies: a statement from the AHA Council on Epidemiology and Prevention; AHA Statistics Committee; World Heart Federation Council on Epidemiology and Prevention; the European Society of Cardiology Working Group on Epidemiology and Prevention; Centers for Disease Control and Prevention; and the National Heart, Lung, and Blood Institute. *Circulation* 2003;108: 2543–9.
40. Costa FM, Ferreira J, Aguiar C, et al. Impact of ESC/ACCF/AHA/WHF universal definition of myocardial infarction on mortality at 10 years. *Eur Heart J* 2012;33:2544–50.
41. McFalls EO, Ward HB, Moritz TE, et al. Coronary-artery revascularization before elective major vascular surgery. *New Engl J Med* 2004;351:2795–804.
42. Rodseth RN, Biccard BM, Chu R, et al. Postoperative B-type natriuretic peptide for prediction of major cardiac events in patients undergoing noncardiac surgery: systematic review and individual patient meta-analysis. *Anesthesiology* 2013;119:270–83. doi:10.1097/ALN.0b013e31829083f1.
43. Lanier WL. Using database research to affect the science and art of medicine. *Anesthesiology* 2010;113:268–70.
44. Halpin RJ, Sugrue PA, Gould RW, et al. Standardizing care for high-risk patients in spine surgery: the Northwestern high-risk spine protocol. *Spine* 2010;35:2232–8.