Association Between Postoperative Troponin Levels and 30-Day Mortality Among Patients Undergoing Noncardiac Surgery

The Vascular Events In Noncardiac Surgery Patients Cohort Evaluation (VISION) Study Investigators

WORLDWIDE, MORE THAN 200 million adults have major noncardiac surgery annually.1,2 Despite benefits associated with surgery, major perioperative complications, including death, occur.3 More than 1 million adults worldwide will die within 30 days of noncardiac surgery each year.1,2

Perioperative risk estimation identifies patients who require more intensive monitoring and management in the postoperative period. Current preoperative risk prediction models for 30-day mortality have limitations.3,4 Some clinicians advocate monitoring troponin measurements after vascular surgery,5 and inconclusive evidence suggests that troponin measurements after abdominal aortic surgery may enhance prediction of short-term mortality.1 Little is known about optimal troponin thresholds for predicting mortality after noncardiac surgery.

A large international study called the VISION Study (Vascular Events in Noncardiac Surgery Patients Cohort Evaluation; clinicaltrials.gov identifier, NCT00512109) is evaluating major complications after noncardiac surgery. Participating patients have troponin T (TnT) levels measured after noncardiac surgery. We assessed the relationship between the peak fourth-generation TnT measurement after noncardiac surgery and 30-day mortality.

Context Of the 200 million adults worldwide who undergo noncardiac surgery each year, more than 1 million will die within 30 days.

Objective To determine the relationship between the peak fourth-generation troponin T (TnT) measurement in the first 3 days after noncardiac surgery and 30-day mortality.

Design, Setting, and Participants A prospective, international cohort study that enrolled patients from August 6, 2007, to January 11, 2011. Eligible patients were aged 45 years and older and required at least an overnight hospital admission after having noncardiac surgery.

Main Outcome Measures Patients’ TnT levels were measured 6 to 12 hours after surgery and on days 1, 2, and 3 after surgery. We undertook Cox regression analysis in which the dependent variable was mortality until 30 days after surgery, and the independent variables included 24 preoperative variables. We repeated this analysis, adding the peak TnT measurement during the first 3 postoperative days as an independent variable and used a minimum P value approach to determine if there were TnT thresholds that independently altered patients’ risk of death.

Results A total of 15 133 patients were included in this study. The 30-day mortality rate was 1.9% (95% CI, 1.7%-2.1%). Multivariable analysis demonstrated that peak TnT values of at least 0.02 ng/mL, occurring in 11.6% of patients, were associated with higher 30-day mortality compared with the reference group (peak TnT ≤0.01 ng/mL): peak TnT of 0.02 ng/mL (adjusted hazard ratio [aHR], 2.41; 95% CI, 1.33-3.77); 0.03 to 0.29 ng/mL (aHR, 5.00; 95% CI, 3.72-6.76); and 0.30 ng/mL or greater (aHR, 10.48; 95% CI, 6.25-16.62). Patients with a peak TnT value of 0.01 ng/mL or less, 0.02, 0.03-0.29, and 0.30 or greater had 30-day mortality rates of 1.0%, 4.0%, 9.3%, and 16.9%, respectively. Peak TnT measurement added incremental prognostic value to discriminate those likely to die within 30 days for the model with peak TnT measurement vs without (C index=0.85 vs 0.81; difference, 0.4; 95% CI, 0.2-0.5; P <.001 for difference between C index values). The net reclassification improvement with TnT was 25.0% (P <.001).

Conclusion Among patients undergoing noncardiac surgery, the peak postoperative TnT measurement during the first 3 days after surgery was significantly associated with 30-day mortality.

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Methods

Study Design and Eligibility Criteria The VISION Study is a prospective cohort study of a representative sample of patients undergoing noncardiac surgery. VISION was designed to recruit 40,000 patients in North and South America, Africa, Asia, Australia, and Europe to evaluate major complications after noncardiac surgery. At the beginning of this study, patients had fourth-generation TnT measurements after noncardiac surgery. The first 15,000 pa-
patients experienced event rates at approximately 3 times what was expected. Recognizing that we had sufficient events to address our objectives related to the fourth-generation TnT measurements, the operations committee decided to henceforth monitor the fifth-generation high-sensitivity TnT assay. This publication is restricted to patients during the period of fourth-generation TnT use.

Eligible patients for the VISION Study had noncardiac surgery, were at least 45 years of age, received a general or regional anesthetic, and underwent elective, urgent, or emergency surgery during the day or at night on a weekday or weekend. Additional eligibility criteria restricting patients to those with data allowing prognostic evaluation of fourth-generation TnT included patients who had a fourth-generation TnT assay measurement and complete data for the 24 potential preoperative predictors of 30-day mortality that we evaluated. Patients were excluded if they did not require an overnight hospital admission after surgery, were previously enrolled in the VISION Study, or declined consent. Patients eligible but not enrolled.

Procedures
Research personnel interviewed and examined patients and reviewed medical records to obtain information on potential predictors of major perioperative complications. At each site, an investigator reviewed and approved all data. Patients had blood collected to measure a Roche 4th-generation Elecsys TnT assay 6 to 12 hours postoperatively and on the first, second, and third days after surgery. Patients enrolled between 12 and 24 hours after surgery had a TnT drawn immediately, and testing continued as previously reported. All TnT measurements were analyzed at the participating hospitals. TnT results were reported to the attending physicians.

Throughout each patient’s hospital stay, research personnel performed clinical evaluations, reviewed medical records, ensured patients had TnT measurements drawn, and noted outcome events. The primary outcome was mortality at 30 days after surgery. Centers also reported the cause of death (vascular or nonvascular, definitions in eAppendix 2 available at http://www.jama.com). Patients were phoned at 30 days after surgery. If patients (or next of kin) indicated the occurrence of an outcome, their physicians were contacted to obtain documentation. Research personnel at participating centers submitted the case report forms and supporting documentation directly to the data management system (iDataFax, coordinating center, McMaster University, Hamilton, Ontario, Canada).

Data monitoring in VISION consisted of central data consistency checks, statistical monitoring, and on-site monitoring for all centers. For the on-site monitoring, the central coordinator randomly selected participants with and without a perioperative complication, and independent monitors audited their medical records and all other supporting documents. No center stood out regarding results from central data consistency checks or statistical monitoring. On-site monitoring demonstrated no major discrepancies between the submitted data and the monitoring findings, except for a systematic error in recording the duration of perioperative hemodynamic compromise at 2 centers. This was corrected and subsequent on-site monitoring of these 2 centers demonstrated no substantial errors.

Statistical Analyses
The analyses related to the association between TnT and 30-day mortality were planned prior to evaluating any of the data. Patients who did not complete the 30-day follow-up were censored on the last day their vital status was known. We determined the percentage of patients who died within 30 days after surgery and the associated 95% CI. We undertook a Cox proportional hazards model in which the dependent variable was mortality until 30 days after surgery, and the independent variables included 24 preoperative variables (eAppendix 3). The model was repeated adding the peak fourth-generation TnT measurement during the first 3 days after surgery as an independent variable and a minimum P value approach was used to determine if there were TnT threshold values that independently altered the patients’ risk of mortality. This approach evaluated every possible threshold of TnT (eg, ≤0.01 vs >0.01; ≤0.02 vs >0.02) in the multivariable model with the 24 preoperative variables. This analysis showed the TnT value that demonstrated the smallest statistically significant P value was a TnT threshold that independently predicted 30-day mortality. Subsequently, this threshold was fixed and the multivariable analysis was repeated to determine if there was another statistically significant threshold.
in addition to the first threshold. The multivariable analysis was repeated un-

til we were no longer able to identify an-

other statistically significant TnT thresh-

old. The Kruskal-Wallis test was used to

identify any statistically significant dif-

ferences in the median time from the

peak TnT value to death across the TnT

thresholds that independently pre-

dicted mortality.

For all independent predictors of

30-day mortality, we report the

adjusted hazard ratio (aHR), 95% CI,

and associated P value (a priori

2-sided α = .05 was designated as sta-

tistically significant). For the TnT

thresholds that independently pre-

dicted 30-day mortality, we deter-

mined the aHRs and their 95% CIs

through bootstrapping 1000 samples.

We undertook a random-effects

(frailty) Cox model to adjust for any

potential site-clustering effect.9 We

calculated the population attributable

risk for the independent predictors of

30-day mortality.10,11 The population

attributable risk represents the pro-

portion of all deaths potentially attrib-

utable to the relevant risk factor (eg, an

elevated TnT measurement) if causality were proven. For the TnT

thresholds that independently pre-

dicted 30-day mortality, we deter-

mined the likelihood ratios. For the

model that included the peak TnT

measurement, discrimination was as-

sessed through evaluation of the C

index and calibration with a

goodness-of-fit test.12-14 The differ-

cence in the C index between the model

that included the peak TnT measure-

ment and the model that only included

preoperative variables was examined

using 1000 bootstrap samples. Assess-

ment of improved risk classification,

as demonstrated in the model that

included the peak TnT measurement

vs the model that only included pre-

operative variables, was made by

calculating the net reclassification

improvement.13 For this analysis we

classified 30-day mortality as low risk

(<1%), intermediate risk (1%-5%),

high risk (>5%-10%), and very high

risk (>10%).

In patients for whom preoperative

creatinine was measured, we analyzed

whether there was an interaction be-

tween patients’ preoperative esti-

mated glomerular filtration rate
eGFR (<30 mL/min per 1.73 m2 or

receiving dialysis, 30 to 44 mL/min per

1.73 m2, 45 to 59 mL/min per

1.73 m2, and ≥60 mL/min per 1.73

m2)16,17 and the TnT thresholds that

independently predicted 30-day mor-

tality. For these analyses, we used a

Cox proportional hazard model that

incorporated a test for interaction and

a priori α = .01 was designated as sta-
tistically significant.

We undertook sensitivity analyses

that excluded patients with a preop-

erative history of coronary artery dis-

ease, recent high-risk coronary artery
disease, or congestive heart failure

and a separate analysis excluding

patients who died within 36 hours

after surgery. In the sensitivity analy-

ses that included the other preopera-
tive variables, we determined if the

TnT thresholds established in our

model that included the peak TnT

measurement continued to predict

30-day mortality. Additional sensi-
tivity analyses were used to determine if the

TnT thresholds that indepen-
dently predict overall 30-day mortal-

ity predicted both vascular mortality

and nonvascular mortality, based on

the center’s determination of the

cause of death.

For all models, forced simultaneous

entry (all candidate variables re-

mained in the model) was used rather than

automated stepwise selection because

simulations demonstrate a higher

risk of overfitting with the latter ap-

proach.18,19 We assessed collineari-

ty using the variance inflation factor that

measures the extent to which the vari-
nce of the model coefficients are

inflated (because of the correlation of a

variable with other predictor vari-

ables) if that variable is included in the

model. We considered variables with a

variance inflation factor of greater

than 10 to be colinear.20 All analyses

were performed using SAS version 9.2,

except for the random-effect (frailty)

Cox model that was performed using


RESULTS

Figure 1 reports the patient flow. Of

the 15133 patients included in the

VISION fourth-generation TnT prog-

nostic study, 99.7% of the patients

completed the 30-day follow-up. Centers

that recruited patients from August 6,

2007 to January 11, 2011, are listed by

location and number of patients in

eTable 1.

eTable 2 reports the preoperative pa-

tient characteristics and the type of sur-

gery. Approximately 1 in 4 patients

(24.2%) were at least 75 years of age and

51.5% were women. The most com-

mon vascular risk factors were hyper-

tension (50.9%) and diabetes (19.5%),

and 26.5% of the patients had active

cancer. The most common surgeries

were major orthopedic surgery (20.4%),

major general surgery (20.3%), and

low-risk surgeries (39.4%). The me-

dian number of fourth-generation TnT

measurements in the first 3 days after

surgery was 3 (interquartile range [IQR]

2-4).

The 30-day mortality rate was 1.9%

(282 deaths; 95% CI, 1.7%-2.1%), with

26.6% dying after hospital discharge

(median time from discharge to death

was 11.0 days; IQR, 4.0-15.0 days).

Table 1 presents the results of the pre-

operative Cox proportional hazards

model. Eleven of the 24 variables as-

sessed were independent predictors of

30-day mortality. Urgent/emergency

surgery was the strongest preopera-
tive predictor of 30-day mortality (aHR,

4.62; 95% CI, 3.57-5.98).

Using a minimum P value ap-

proach, multivariable analysis demon-

strated that peak TnT threshold values

of 0.02 ng/mL, 0.03 ng/mL, and

0.30 ng/mL were independently asso-

ciated with 30-day mortality (Table 1).

The random-effects (frailty) Cox model

that adjusted for any potential site clus-

tering effect produced similar results.

A history of congestive heart failure and

major vascular surgery independently

predicted mortality in the preopera-
tive model, but not in the model in-
The strongest independent predictors of 30-day mortality were a peak TnT value of 0.03 to 0.29 ng/mL (aHR, 5.00; 95% CI, 3.72-6.76) and 0.30 ng/mL or greater (aHR, 10.48; 95% CI, 6.25-16.62). The independent prognostic factors identified in this model potentially explain the majority of the deaths that occurred (ie, the total population attributable risk was 89.0%; 95% CI, 85.3-92.4); the prognostically relevant peak TnT values had the largest population attributable risk (41.8%).

Peak TnT values of 0.01 ng/mL or less, 0.02 ng/mL, 0.03 to 0.29 ng/mL, and 0.30 ng/mL or greater occurred in 88.4%, 3.3%, 7.4%, and 0.9% of the patients, respectively. The incidence of 30-day mortality was 1.0%, 4.0%, 9.3%, and 16.9% in patients with a peak TnT values of 0.01 or less, 0.02, 0.03 to 0.29, and 0.30 ng/mL or greater, respectively. eTable 3 reports the likelihood ratios for these TnT thresholds. Patients with TnT values that were independently associated with mortality demonstrated the following median times from the peak TnT measurement to death: 0.02 ng/mL (13.5 days; IQR, 8.5-20 days); 0.03 to 0.29 ng/mL (9.0 days; IQR, 3.5-16 days); and 0.30 ng/mL or greater (6.5 days; IQR, 1.5-15 days), \( P = .01 \) for differences among time to death. Figure 2 reports Kaplan-Meier estimates for death based on the peak TnT values.

eTable 4 reports the results of our sensitivity analysis that excluded patients who had preoperative history of coronary artery disease, recent high-risk coronary artery disease, or congestive heart failure, and eTable 5 reports the results of our sensitivity analysis that excluded patients who died within the first 36 hours after surgery. Both sensitivity analyses demonstrated that results for the TnT thresholds did not appreciably differ from the model that included all 15 133 patients.

Each variable included in the models demonstrated a variance inflation factor of less than 10, suggesting no collinearity. The model that included the peak TnT measurement demonstrated good calibration (goodness-of-fit test \( P = .43 \)). The model that included the peak TnT measurement demonstrated good discrimination, as did the preoperative model without TnT measurement (C index=0.85 vs 0.81; \([\text{difference, 0.4; 95% CI, 0.2-0.5}]\) \( P < .001 \) for difference between C index values). Among the patients who died, the percentage correctly reclassified to a higher risk category with the model that included the peak TnT measurement compared with the model that only included preoperative risk factors was 18.8% (Table 2). Among the patients who survived, the percentage correctly reclassified to a lower risk category with the model that included the peak TnT measurement compared with the model that only included preoperative risk factors was 6.2%. The net reclassification improvement associated with TnT measurement was 25.0% (95% CI, 17.2%-32.8%; \( P < .001 \)).

Of the 14 008 (92.6%) patients in whom preoperative creatinine levels were measured, 520 patients (3.7%) had an eGFR of less than 30 mL/min per 1.73 m² or were receiving dialysis; 760 patients (5.4%) had an eGFR of 30 to 44 mL/min per 1.73 m²; 1496 patients (10.7%) had an eGFR of 45 to 59 mL/min per 1.73 m²; and 11 232 patients (80.2%) had an eGFR of at least 60 mL/min per 1.73 m². There was no interaction between preoperative eGFR and the TnT thresholds (P = .05).

Among the 282 patients who died within 30 days of surgery, centers reported a vascular cause of death in 127 patients (45.0%) and a nonvascular cause in 155 patients (55.0%). Table 3 reports the independent predictors of 30-day vascular mortality and nonvascular mortality separately. The results for the TnT thresholds that independently predicted 30-day mortality were not appreciably different for vascular and nonvascular mortality. Among patients who experienced a TnT elevation 0.02 ng/mL or greater, this occurred at 6 to 12 hours after surgery, post-
operative day 1, postoperative day 2, and postoperative day 3 in 45.9%, 28.3%, 17.7%, and 8.2% of these patients, respectively. Considering the most serious nonvascular complications, the median time to a diagnosis of pneumonia was 6.0 days (IQR, 3.0-12.0 days), and the median time to a diagnosis of sepsis was 7.0 days (IQR, 4.0-12.0 days).

Table 1. Models to Predict 30-Day Mortality

<table>
<thead>
<tr>
<th>Potential Risk Factor</th>
<th>Death Within 30 Days Postsurgery</th>
<th>Preoperative Variables Only</th>
<th>Preoperative Variables and Peak TnT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Died/Total No.</td>
<td>% (95% CI)</td>
<td>aHR (95% CI)</td>
</tr>
<tr>
<td>Age, y</td>
<td>45-64</td>
<td>68/7697</td>
<td>0.9 (0.7-1.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65-74</td>
<td>69/3779</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥75</td>
<td>146/3657</td>
</tr>
<tr>
<td>Recent high-risk CAD</td>
<td>No recent high-risk CAD</td>
<td>15/173</td>
<td>8.7 (5.3-13.8)</td>
</tr>
<tr>
<td>PVD history</td>
<td>No PVD history</td>
<td>45/809</td>
<td>5.6 (4.2-7.4)</td>
</tr>
<tr>
<td>Stroke history</td>
<td>No stroke history</td>
<td>42/898</td>
<td>6.0 (4.5-8.1)</td>
</tr>
<tr>
<td>COPD</td>
<td>No COPD</td>
<td>65/1282</td>
<td>5.1 (4.0-6.4)</td>
</tr>
<tr>
<td>Active cancer</td>
<td>No active cancer</td>
<td>106/4015</td>
<td>2.6 (2.2-3.2)</td>
</tr>
<tr>
<td>Urgent/emergency surgery</td>
<td>No urgent/emergency surgery</td>
<td>123/1412</td>
<td>5.7 (4.8-6.8)</td>
</tr>
<tr>
<td>Major general surgery</td>
<td>No major general surgery</td>
<td>113/3076</td>
<td>3.7 (3.1-4.4)</td>
</tr>
<tr>
<td>Major neurosurgery</td>
<td>No major neurosurgery</td>
<td>25/888</td>
<td>2.8 (1.9-4.1)</td>
</tr>
<tr>
<td>Peak TnT measurement</td>
<td>&lt;0.01 ng/mL</td>
<td>134/1376</td>
<td>1.0 (0.8-1.2)</td>
</tr>
<tr>
<td></td>
<td>0.02 ng/mL</td>
<td>20/494</td>
<td>4.0 (2.6-6.2)</td>
</tr>
<tr>
<td></td>
<td>0.03-0.29 ng/mL</td>
<td>104/1121</td>
<td>9.3 (7.7-11.1)</td>
</tr>
<tr>
<td></td>
<td>≥0.30 ng/mL</td>
<td>24/142</td>
<td>16.9 (11.6-23.9)</td>
</tr>
</tbody>
</table>

Predictive in the Preoperative Model but Not Predictive in the Model That Included TnT Measurements

<table>
<thead>
<tr>
<th>Potential Risk Factor</th>
<th>Death Within 30 Days Postsurgery</th>
<th>Preoperative Variables Only</th>
<th>Preoperative Variables and Peak TnT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Died/Total No.</td>
<td>% (95% CI)</td>
<td>aHR (95% CI)</td>
</tr>
<tr>
<td>CHF history</td>
<td>No CHF history</td>
<td>37/793</td>
<td>5.3 (3.8-7.2)</td>
</tr>
<tr>
<td>Major vascular surgery</td>
<td>No major vascular surgery</td>
<td>19/504</td>
<td>3.8 (2.4-5.8)</td>
</tr>
<tr>
<td>Major vascular surgery</td>
<td>No major vascular surgery</td>
<td>263/14629</td>
<td>1.8 (1.6-2.0)</td>
</tr>
<tr>
<td>CAD history</td>
<td>No CAD history</td>
<td>56/1382</td>
<td>3.2 (2.4-3.9)</td>
</tr>
<tr>
<td>Cardiac arrest history</td>
<td>No cardiac arrest history</td>
<td>1/88</td>
<td>1.5 (0.3-7.9)</td>
</tr>
<tr>
<td>TIA history</td>
<td>No TIA history</td>
<td>7/376</td>
<td>1.9 (0.9-3.8)</td>
</tr>
<tr>
<td>DVT or PE history</td>
<td>No DVT or PE history</td>
<td>11/475</td>
<td>2.3 (1.3-4.1)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>No diabetes</td>
<td>74/2952</td>
<td>2.5 (2.0-3.1)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>No hypertension</td>
<td>180/7709</td>
<td>2.3 (2.0-2.7)</td>
</tr>
<tr>
<td>Obstructive sleep apnea</td>
<td>No obstructive sleep apnea</td>
<td>11/773</td>
<td>1.4 (0.8-2.5)</td>
</tr>
<tr>
<td>Major orthopedic surgery</td>
<td>No major orthopedic surgery</td>
<td>63/10394</td>
<td>2.0 (1.6-2.6)</td>
</tr>
<tr>
<td>Major URO/GYN surgery</td>
<td>No URO/GYN surgery</td>
<td>10/1886</td>
<td>0.5 (0.3-1.5)</td>
</tr>
<tr>
<td>Major thoracic surgery</td>
<td>No major thoracic surgery</td>
<td>7/376</td>
<td>1.9 (0.9-3.8)</td>
</tr>
</tbody>
</table>

Abbreviations: aHR, adjusted hazard ratio; AR, attributable risk; CAD, coronary artery disease; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; DVT, deep venous thrombosis; GYN, gynecological; NA, not applicable; PE, pulmonary embolus; PVD, peripheral vascular disease; TnT, troponin T, URO, urological.

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COMMENT

In this international prospective cohort study of 15,133 patients who were at least 45 years of age and underwent noncardiac surgery that required hospital admission, multivariable analysis demonstrated that fourth-generation peak TnT thresholds of 0.02 ng/mL, 0.03 ng/mL, and 0.30 ng/mL independently predicted 30-day mortality. Peak TnT values after noncardiac surgery proved the strongest predictors of 30-day mortality, and the population attributable risk analysis suggested elevated TnT measurements after surgery may explain 41.8% of the deaths. Based on the identified peak TnT values, there were marked increases in the absolute risk of 30-day mortality (ie, 1.0% for a TnT value ≤0.01 ng/mL; 4.0% for a value of 0.02 ng/mL; 9.3% for a value of 0.03-0.29 ng/mL; and 16.9% for a value ≥0.30 ng/mL). 11.6% of patients had a prognostically relevant peak TnT value of at least 0.02 ng/mL. The higher the peak TnT value, the shorter the median time to death. Our net reclassification improvement analysis demonstrated that monitoring TnT values for the first 3 days after surgery substantially improved 30-day mortality risk stratification compared with assessment limited to preoperative risk factors.

Table 2. Net Reclassification Improvement of Predicted Probability of 30-Day Mortality With the Model That Included the Peak TnT Measurement Compared With the Model Based Only on the Preoperative Risk Factors

<table>
<thead>
<tr>
<th>Preoperative Risk Factors Only</th>
<th>Died, No.</th>
<th>Survived, No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1%</td>
<td>1%-5%</td>
</tr>
<tr>
<td>Includes Peak TnT Measurement</td>
<td>25</td>
<td>16</td>
</tr>
<tr>
<td>≤0.01</td>
<td>10</td>
<td>68</td>
</tr>
<tr>
<td>0.02-0.29</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>0.30</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Abbreviation: TnT, troponin T.

**Strengths and Limitations**

Strengths of this study include the large sample of patients undergoing noncardiac surgery from 8 countries in 5 continents. Our results were consistent across sites for the TnT thresholds, suggesting they are relevant to contemporary surgery worldwide. All patients had the same fourth-generation TnT assay measured after surgery. A total of 99.7% of the patients completed the 30-day follow-up. We had complete data on the 24 preoperative variables that we evaluated. The model that included the peak TnT measurement demonstrated good discrimination and calibration.

Rather than evaluating predetermined values, we statistically identified prognostically relevant TnT thresholds. Thresholds based on 99th percentiles or coefficients of variation of less than 10%, although commonly used, are arbitrary. Studies that demonstrate worse prognosis above these thresholds do not confirm these thresholds are where risk is actually changing. Such results may be driven by the poor outcomes of patients with TnT measurements substantially above these thresholds. Further, some patients with troponin values immediately below these thresholds may have poor outcomes, but their signal may get washed out by the larger patient population with even lower troponin values who have few or no events. It is for this reason that we believe statistically...
identifying prognostically relevant TnT thresholds based on the actual data are a more appropriate method.

This study also has limitations. We did not measure a TnT value prior to surgery and cannot comment on how a preoperative value would impact risk prediction. We only measured the fourth-generation TnT assay, and therefore cannot comment on the prognostic relevance of other troponin assays. Despite our large sample size, only 1263 patients had a peak troponin threshold of 0.03 ng/mL or greater. Therefore, it is possible with an even larger cohort that we may have identified another statistically significant and prognostically relevant TnT threshold between 0.03-0.29 ng/mL and at greater than 0.30 ng/mL. Although we did not demonstrate an interaction between preoperative eGFR and the TnT thresholds, we cannot exclude an interaction, especially at lower levels of renal function. Our results are, however, consistent with a prior large (N=7033) acute coronary syndrome study that demonstrated TnT levels predicted 30-day mortality regardless of patients' baseline eGFR. We did not capture whether patients were recruited prior to or after surgery, and therefore we cannot evaluate these subgroups of patients separately. We did not record whether any actions were taken based on the TnT values reported to physicians, and therefore we cannot comment on the potential impact of any such interventions. If physicians implemented therapies based upon these TnT measurements and these interventions impacted 30-day mortality, then our 30-day mortality rates associated with elevated TnT measurements likely represent the mortality rates future unblinded physicians can expect in their clinical practice.

Comparison to Other Studies
Levy et al undertook a meta-analysis of 10 studies (N=1728 patients) that assessed the independent prognostic capabilities of an elevated troponin measurement after noncardiac surgery to predict intermediate-term (<12 months) mortality and demonstrated an odds ratio of 6.7 (95% CI, 4.1-10.9; I²=0%). The studies in this meta-analysis used several different troponin assays, numerous different troponin thresholds, and did not evaluate the impact on short-term mortality (<30 days). Le Manach et al demonstrated in a study of 1136 abdominal aortic surgical cases that a Dade-Behring Troponin I measurement of greater than 1.5 ng/mL was an independent predictor of in-hospital mortality. Our study included a much broader spectrum of noncardiac surgeries and a much larger sample size.

Interpretation
We have demonstrated that the peak fourth-generation TnT measurement in the first 3 days after surgery strongly

### Table 3. Perioperative Independent Predictors of 30-Day Causes of Death (Vascular and Nonvascular) as Reported by Centers

<table>
<thead>
<tr>
<th>Potential Independent Predictors</th>
<th>Vascular Mortality (n = 127)</th>
<th>Nonvascular Mortality (n = 155)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No./No., a % (95% CI)</td>
<td>Adjusted HR (95% CI)</td>
</tr>
<tr>
<td>Age, y</td>
<td>24/769, 0.3 (0.2-0.5)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>65-75</td>
<td>25/779, 0.7 (0.4-1.0)</td>
<td>1.59 (0.90-2.81)</td>
</tr>
<tr>
<td>≥75</td>
<td>79/3657, 2.1 (1.7-2.7)</td>
<td>3.29 (2.03-5.35)</td>
</tr>
<tr>
<td>Recent high-risk CAD</td>
<td>11/173, 6.4 (3.6-11.0)</td>
<td>2.48 (1.30-4.73)</td>
</tr>
<tr>
<td>No recent high-risk CAD</td>
<td>116/14960, 0.8 (0.6-0.9)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>History of PVD</td>
<td>23/809, 2.8 (1.9-4.2)</td>
<td>1.66 (1.03-2.67)</td>
</tr>
<tr>
<td>No history of PVD</td>
<td>104/14324, 0.7 (0.6-0.9)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>History of stroke</td>
<td>28/696, 4.0 (2.8-5.8)</td>
<td>2.66 (1.72-4.10)</td>
</tr>
<tr>
<td>No history of stroke</td>
<td>99/1437, 0.7 (0.6-0.8)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>COPD</td>
<td>36/1282, 2.8 (2.0-3.9)</td>
<td>2.65 (1.78-3.95)</td>
</tr>
<tr>
<td>No COPD</td>
<td>91/13851, 0.7 (0.5-0.8)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Active cancer</td>
<td>29/4015, 0.7 (0.5-1.0)</td>
<td>1.14 (1.02-1.79)</td>
</tr>
<tr>
<td>No active cancer</td>
<td>98/11118, 0.9 (0.7-1.1)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Urgent/emergency surgery</td>
<td>58/2142, 2.7 (2.1-3.5)</td>
<td>3.26 (2.24-4.75)</td>
</tr>
<tr>
<td>No urgent/emergency surgery</td>
<td>69/12991, 0.5 (0.4-0.7)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Major general surgery</td>
<td>36/3076, 1.2 (0.8-1.6)</td>
<td>1.57 (1.04-2.38)</td>
</tr>
<tr>
<td>No major general surgery</td>
<td>91/12057, 0.8 (0.6-0.9)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Major neurosurgery</td>
<td>12/888, 1.4 (0.8-2.3)</td>
<td>2.46 (1.32-4.58)</td>
</tr>
<tr>
<td>No major neurosurgery</td>
<td>115/14245, 0.8 (0.7-1.0)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Peak TnT measurement ≤0.01 ng/mL</td>
<td>56/13376, 0.4 (0.3-0.5)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>≤0.02 ng/mL</td>
<td>7/494, 1.4 (0.7-2.9)</td>
<td>1.65 (0.74-3.67)</td>
</tr>
<tr>
<td>≤0.03-0.29 ng/mL</td>
<td>51/1121, 4.5 (2.5-5.9)</td>
<td>4.81 (3.18-7.25)</td>
</tr>
<tr>
<td>≥0.30 ng/mL</td>
<td>13/142, 9.2 (5.4-15.0)</td>
<td>10.01 (5.30-18.90)</td>
</tr>
</tbody>
</table>

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predicts 30-day mortality and may explain a substantial proportion of the deaths (41.8%). Compared with our preoperative model, the model that included the peak TnT measurement demonstrated an absolute increase in the C index value of 0.04. We also classified 30-day mortality as low risk (<1%), intermediate risk (1%-5%), high risk (>5%-10%), and very high risk (>10%) and with our model that included the peak TnT measurement, we demonstrated among patients who died and also among those who survived an improvement in reclassification of 18.8% and 6.2%, respectively. Although these data suggest improvement in risk classification with postoperative troponin measurements, what is now required is to undertake clinical trials to determine if this risk is modifiable.

Based on the guideline recommendation that abnormal troponin values should have a coefficient of variation less than 10%, many laboratories consider a fourth-generation TnT measurement of at least 0.04 ng/mL abnormal.23,24 Our study suggests that TnT values of less than the commonly used threshold of 0.04 ng/mL (ie, 0.02 ng/mL and 0.03 ng/mL) are, in the context of noncardiac surgery, strongly associated with 30-day mortality. Given that troponin biomarkers have nearly absolute myocardial tissue specificity and the median time to death from a peak TnT value of 0.02 ng/mL (ie, 13.5 days) and 0.03 ng/mL (9.0 days), these lower TnT values may represent a warning myocardial insult.25

Consideration that more than 200 million adults undergo major noncardiac surgery annually,1 potentially half of these patients are at least 45 years of age,2 and 11.6% of the patients in our study had a peak TnT value of at least 0.02 ng/mL, suggests that worldwide more than 10 million adults may have prognostically relevant troponin values after noncardiac surgery each year. Although no randomized controlled trial has established an effective treatment for patients with an elevated troponin measurement after noncardiac surgery, the prognosis of these patients may be modifiable. First, the high-quality evidence for acetylsalicylic acid (ASA) and statin therapy in the nonoperative setting,20,27 and encouraging observational data from a large international perioperative trial showing an association with use of these drugs and decreased 30-day mortality in patients who have experienced a perioperative myocardial injury,28 suggests that ASA and statin therapy may benefit patients with an elevated perioperative troponin measurement. We have previously demonstrated that a substantial proportion of patients experiencing a myocardial injury after noncardiac surgery do not receive these drugs.28 Second, the timeline from the peak TnT value until death demonstrates that there is time to intervene.

Third, although study centers deemed approximately half the deaths as having nonvascular causes, it is possible that these events may also be modifiable through enhanced cardiovascular management. Because the majority of patients who experience a perioperative myocardial infarction after noncardiac surgery do not experience ischemic symptoms,28 physicians may have missed diagnosing some of the patients with a prognostically relevant TnT value after surgery as having a cardiac event.

Further, undiagnosed and untreated myocardial injury may decrease the likelihood of surviving a nonvascular complication. For example, although pneumonia is a serious complication that can result in death after noncardiac surgery,29 it is possible that patients who first experience a myocardial injury may have a higher likelihood of developing pneumonia, a greater risk of dying if they do develop pneumonia, or both. In this study, 74.2% of patients who would develop an elevated TnT measurement did so within the first 24 hours after surgery, whereas the median time to develop pneumonia was 6 days after surgery. These considerations may explain the association between the prognostically relevant TnT thresholds and nonvascular death in our sensitivity analysis, and suggest that intervention in those with elevated troponin could decrease deaths classified as nonvascular.

Although noncardiac surgery has enormous potential to help patients, many patients die within 30 days of surgery (1.9% in VISION). Our study demonstrates that prognostically relevant TnT measurements after surgery strongly predict who will die within 30 days of surgery. Although at present, troponin measurements are not commonly measured after noncardiac surgery, the simplicity of this test and its prognostic power suggest it may have substantial clinical utility. There is now a need for large randomized controlled trials to evaluate potential interventions to mitigate the high risk of death in patients who have an elevated troponin measurement after noncardiac surgery.

CONCLUSIONS

The peak fourth-generation TnT measurement in the first 3 days after noncardiac surgery is strongly associated with 30-day mortality. Our data suggest that 1 in 25 patients with a peak TnT measurement of 0.02 ng/mL, 1 in 11 patients with a peak TnT measurement of 0.03 to 0.29 ng/mL, and 1 in 6 patients with a peak TnT measurement of at least 0.30 ng/mL will die within 30 days of surgery. Monitoring postoperative TnT measurements can enhance risk stratification after noncardiac surgery. Although there are some encouraging observational data, clinical trials are needed to establish whether interventions can alter patients’ risk of death based on an elevated troponin measurement after surgery.

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Online-Only Material: eTables 1 through 5 are available at http://www.jama.com.
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