Troponin T monitoring to detect myocardial injury after noncardiac surgery: a cost–consequence analysis

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Accepted Nov. 17, 2017

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DOI: 10.1503/cjs.010217

Background: Myocardial injury after noncardiac surgery (MINS) is a mostly asymptomatic condition that is strongly associated with 30-day mortality; however, it remains mostly undetected without systematic troponin T monitoring. We evaluated the cost and consequences of postoperative troponin T monitoring to detect MINS.

Methods: We conducted a model-based cost–consequence analysis to compare the impact of routine troponin T monitoring versus standard care (troponin T measurement triggered by ischemic symptoms) on the incidence of MINS detection. Model inputs were based on Canadian patients enrolled in the Vascular Events in Noncardiac Surgery Patients Cohort Evaluation (VISION) study, which enrolled patients aged 45 years or older undergoing inpatient noncardiac surgery. We conducted probability analyses with 10 000 iterations and extensive sensitivity analyses.

Results: The data were based on 6021 patients (48% men, mean age 65 [standard deviation 12] yr). The 30-day mortality rate for MINS was 9.6%. We determined the incremental cost to avoid missing a MINS event as $1632 (2015 Canadian dollars). The cost-effectiveness of troponin monitoring was higher in patient subgroups at higher risk for MINS, e.g., those aged 65 years or more, or with a history of atherosclerosis or diabetes ($1309).

Conclusion: The costs associated with a troponin T monitoring program to detect MINS were moderate. Based on the estimated incremental cost per health gain, implementation of postoperative troponin T monitoring seems appealing, particularly in patients at high risk for MINS.

Contexte : Les lésions myocardiques après chirurgie non cardiaque (CNC) sont majoritairement asymptomatiques et fortement associées au risque de mortalité dans les 30 jours; toutefois, dans la plupart des cas, elles ne sont pas détectées en l'absence d'une surveillance systématique de la troponine T. Nous avons évalué les coûts et les conséquences d'une telle surveillance pour détecter les lésions myocardiques après CNC.

Méthodes : Nous avons mené une analyse coût–conséquence modélisée pour comparer la surveillance systématique de la troponine T aux soins habituels seuls (mesure de la troponine T seulement s'il y a présence de symptômes d'ischémie) sur la fréquence de détection de lésions myocardiques après CNC. Les données ayant servi à l'analyse provenaient des patients canadiens ayant participé à l'étude de cohorte VISION, qui visait à évaluer les complications vasculaires chez les patients de 45 ans et plus ayant subi une CNC. Nous avons mené des analyses de probabilité avec 10 000 itérations et des analyses de sensibilité approfondies.

Résultats : Les données portaient sur 6021 patients (48 % du sexe masculin; âge moyen de 65 ans [écart-type de 12 ans]). Le taux de mortalité dans les 30 jours associé à une lésion myocardique après CNC était de 9,6 %. Nous avons déterminé que le coût marginal de la détection de la présence d'une lésion par surveillance de la troponine T était de 1632 $ (dollars canadiens en 2015). Le rapport coût–efficacité était plus bas pour les sous-groupes de patients à risque élevé de lésion myocardique après CNC, comme les patients de 65 ans et plus ou ceux ayant des antécédents d'athérosclérose ou de diabète (1309 $), que pour leurs pairs.

Conclusion : Les coûts associés à un programme de surveillance de la troponine T pour détecter les lésions myocardiques après CNC étaient modérés. Le coût marginal estimé par gain de santé indique que la mise en œuvre de ce type de programme pourrait être une option intéressante, surtout pour les patients à risque élevé de lésion myocardique après CNC.

About 500 000 noncardiac surgical procedures take place in Canada annually.[1] In the Vascular Events in Noncardiac Surgery Patients Cohort Evaluation (VISION) study, myocardial injury after noncardiac surgery (MINS) (defined as a peak troponin T level ≥ 0.03 ng/mL due to myocardial ischemia) was the most frequent vascular complication (8%).[2] The crude 30-day mortality rate of MINS was 9.6%, and MINS was strongly associated with death. It may account for 34% of deaths within this period.[2]

Because only a small minority of patients who experience MINS have symptoms,[2] most cases go undetected without systematic postoperative troponin T monitoring. Monitoring for MINS by means of perioperative troponin T levels may offer an opportunity to intervene and potentially reduce subsequent adverse events. Although the optimal treatment for MINS remains unclear, promising observational data suggest mortality advantages in patients given treatments after MINS and, thus, that MINS is likely modifiable.[3,4] Moreover, in the VISION study, patients with MINS who died did so a mean of 9 days after their initial troponin T level elevation, which indicates that there is time to initiate treatment after MINS is detected. Perhaps as a consequence, Canadian[5] and international[6] guidelines recommend troponin monitoring after noncardiac surgery in patients at high cardiovascular risk.

The need to be judicial with resources requires consideration of both benefit and cost of any intervention.[7,8] Information on the resource and health implications of routine troponin T monitoring after noncardiac surgery is limited. The goal of this initial, basic model was to estimate, using different postoperative troponin T monitoring strategies, the cost and health consequences resulting from routine troponin T monitoring in patients with various levels of preoperative MINS risk undergoing noncardiac surgery, with a focus on the detection of MINS (that is, without burdening the model with assumptions with regard to treatment effect).

Methods

The basis for these cost–consequence analyses was the VISION Study (clinicaltrials.gov, identifier NCT00512109). A previous report presents the details of enrolment and follow-up.[2] Since the VISION study did not measure resource use, this cost–consequence analysis was model-based.

Population

The VISION study enrolled patients aged 45 years or more who underwent noncardiac surgery that required an overnight hospital stay and who had general or regional anesthesia. This analysis includes all Canadian patients enrolled in the VISION study between September 2007 and October 2010 who had their troponin T level measured with the fourth-generation (non–high-sensitive) assay (Fig. 1). We excluded patients who had an elevated troponin T level in the 7 days before surgery. The research ethics board at each site approved the protocol, and written informed consent was obtained from all patients.

Definition of myocardial injury after noncardiac surgery

We previously established the diagnostic criteria for MINS based on its prognostic impact on 30-day mortality.[2] Details on the adjudication procedure have been previously published;[2] in short, physicians evaluated extensive in-hospital documentation of all patients with troponin elevation for ischemic features fulfilling the universal definition of myocardial infarction[6] and for alternative nonischemic causes for increased troponin levels (i.e., sepsis, pulmonary embolism and cardioversion). Using Cox regression, we analyzed the association between alternative diagnostic criteria for MINS and 30-day mortality after adjustment for preoperative characteristics and perioperative complications. Irrespective of the presence of ischemic symptoms or electrocardiographic changes, a peak troponin T level of 0.03 ng/mL or greater was independently associated with 30-day mortality (adjusted hazard ratio 3.87, 95% confidence interval 2.96–5.08). Therefore, MINS was defined as a troponin T value of 0.03 ng/mL or greater resulting from ischemia that occurs within 30 days after noncardiac surgery.[2] Differentiation between type 1 and type 2 infarction[6] was not attempted.

For these analyses, we considered MINS events detected during the first 3 postoperative days (i.e., during the proposed troponin T monitoring period).

Model structure and computer simulation

We conducted a cost–consequence analysis from the perspective of the Canadian health care system. We measured the health consequences as the number of detected MINS events during the monitoring period. We expressed costs in 2015 Canadian dollars.

In our base-case model, we compared fourth-generation troponin T monitoring 6–12 hours after surgery and on postoperative days 1, 2 and 3 with standard care (i.e., reliance on suggestive myocardial ischemic symptoms to trigger evaluation for potential MINS). The troponin level was not systematically measured preoperatively.

The model was structured as a decision tree (Fig. 2). It included the following health states: true-positive (detected MINS), true-negative (no MINS), false-negative (missed MINS) and false-positive. In the patients screened for elevation of the troponin T level, a false-positive health state was defined as troponin T elevation that was not due to

myocardial ischemia (i.e., sepsis, pulmonary embolism or cardioversion). In the standard care alternative, false-positive referred to patients primarily assessed because of symptoms suggestive of myocardial ischemia (e.g., chest pain) but deemed to be of noncardiac origin after further investigation.

The reference analysis was a probabilistic sensitivity analysis that calculated the mean cost and the mean number of detected events over 10 000 iterations generated by a second-order Monte Carlo simulation. We ran the model in Microsoft Excel spreadsheets with corresponding macros. We validated the model by extreme values and by the number of MINS cases estimated by the model against the primary data. Calibration of cost estimates was not possible because primary cost data were not available.

Data inputs

Data generated for 6021 Canadian VISION study patients informed the probabilities of the monitoring results. Since the VISION study did not include nonscreened patients, we estimated the number of detected and missed cases of MINS after standard care using the number of symptomatic MINS cases (assumed detected in standard care) and the number of asymptomatic MINS cases (assumed undetected in standard care). The VISION study did not collect information on clinical symptoms in patients without elevation of the troponin T level of 0.04 ng/mL or greater. We assumed the incidence of noncardiac chest pain (i.e., false-positive in the standard-care group) to be 1% and explored the impact of this assumption in sensitivity analysis. We opted for this very conservative estimate of false-positive health state to avoid any overestimation of the cost in the standard-care group. Table 1 summarizes the model parameters and their distributions.

The VISION study did not collect data on resource use except for coronary angiography. We estimated the cost of the 2 alternatives based on predefined diagnostic algorithms to confirm or exclude MINS in the case of elevated troponin T levels in screened patients or suggestive symptoms in the standard-care group. The algorithms included fourth-generation troponin T measurements as monitoring

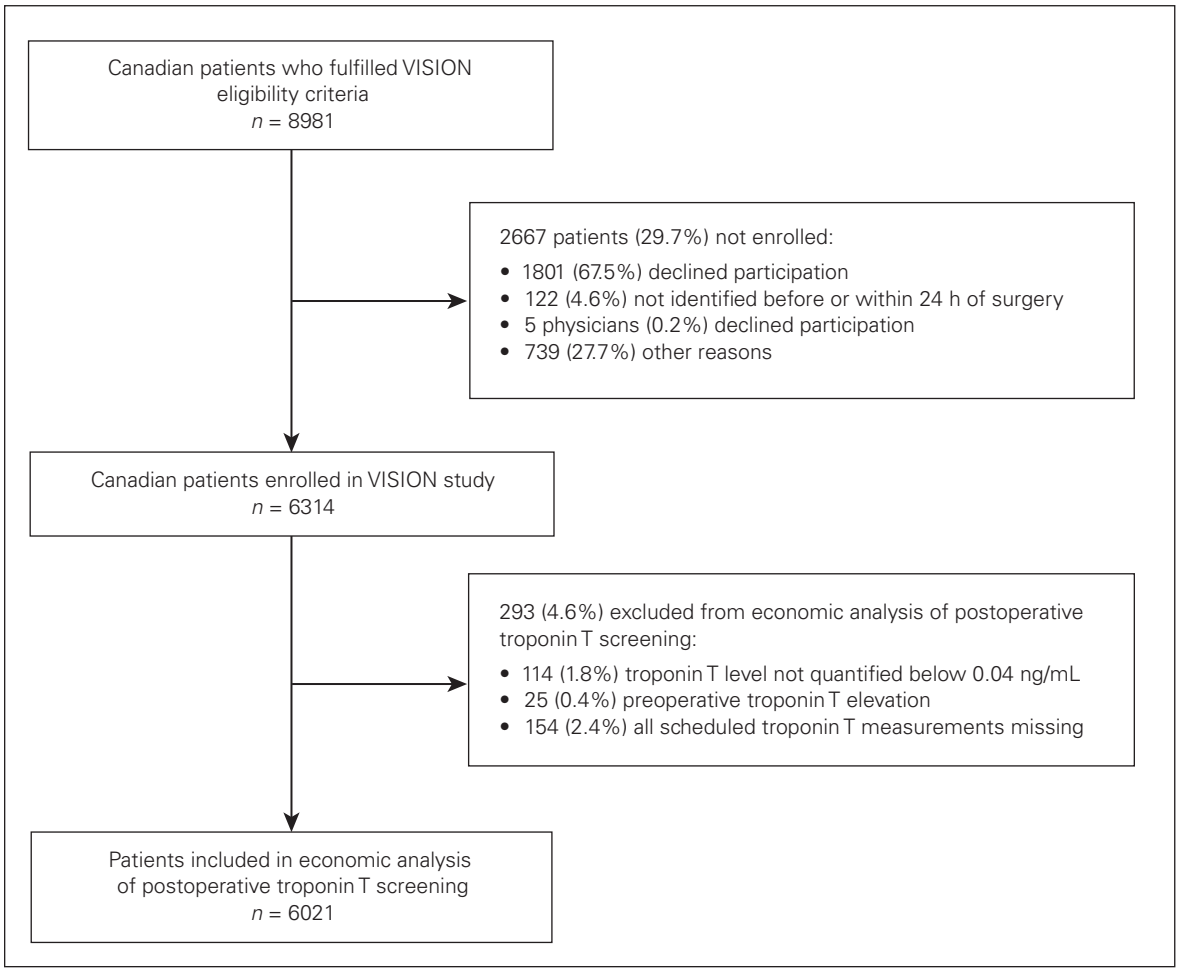

Fig. 1. Flow chart showing selection of study population. Note: VISION = Vascular Events in Noncardiac Surgery Patients Cohort Evaluation.

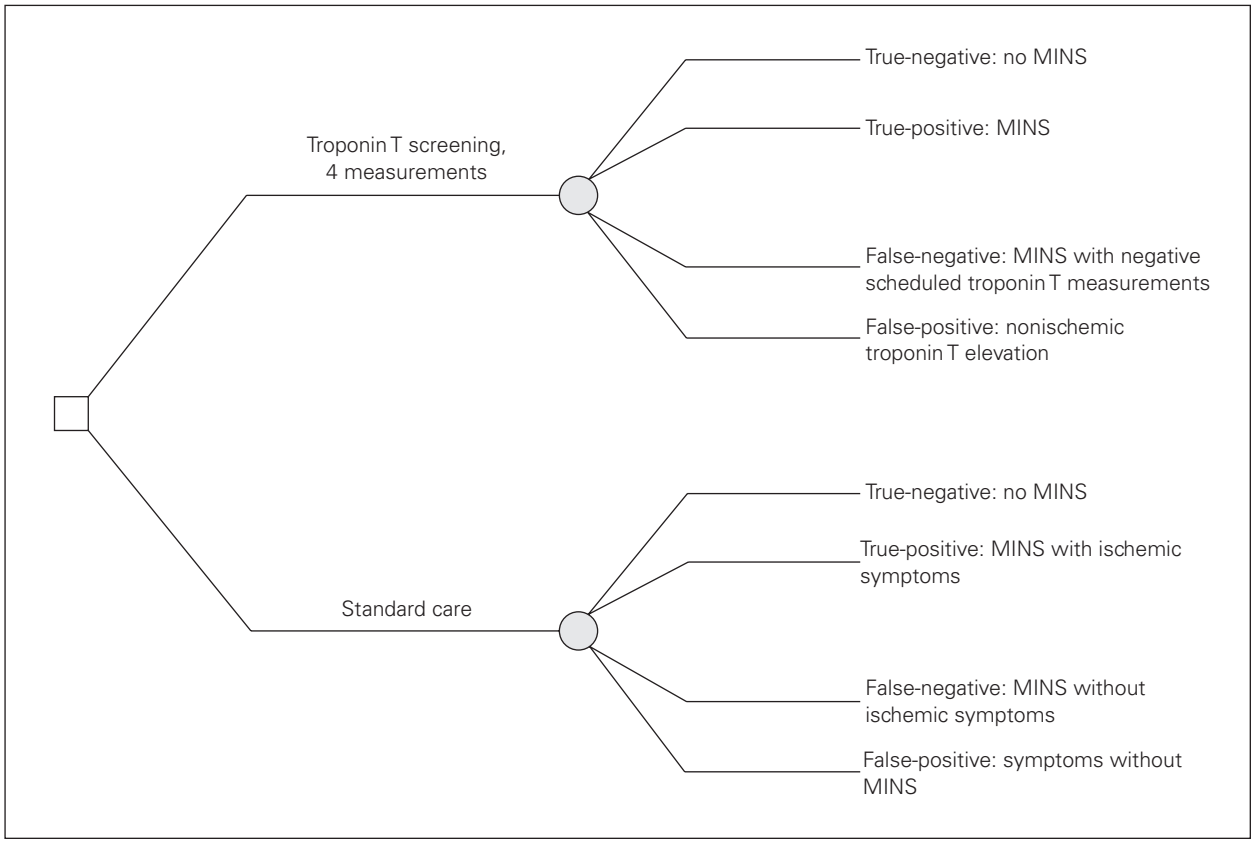

Fig. 2. Decision tree representing the alternatives and the health states at the end of the monitoring period. Note: MINS = myocardial injury after noncardiac surgery.

and as serial follow-up in the case of elevated troponin T or of clinical symptoms (triggered troponin T measurements), a cardiology consultation and follow-up visits, and serial electrocardiography and echocardiography for all patients with elevated troponin T levels. Canadian VISION data were the source for the probability of coronary angiography and for the probability that the troponin T level exceeded the upper limit of normal as late as on the last day of scheduled measurement, thus resulting in additional, triggered troponin T measurements in screened patients. The model did not include costs related to the noncardiac surgical procedure itself because these resource items were identical in the 2 alternatives.[12] Costs were inflated by the Canadian health care Consumer Price Index as necessary.

Sensitivity and scenario analyses

We explored the impact of the assumptions on resource use and costs resulting from the predefined diagnostic algorithms using sensitivity analyses. The worst-case scenario maximized the incremental costs of the monitoring program by assuming simultaneously a 25% cost increase in the screened patients and a 25% cost reduction for standard care. The best-case scenario reduced the incremental cost of the monitoring program by assuming the inverse. We also assessed the impact of the assumption for all patients with elevated troponin T levels to undergo echocardiography by assuming that 50% and 75% of such patients would have echocardiography.

We assessed the impact of varying the false-positive rate in the standard-care patients (imputing 0% for sensitivity analyses and assuming 1% for the reference case). In the overall VISION population (i.e., not limited to Canadian centres), nonischemic causes for troponin elevation were adjudicated in 0.59% of patients (95/16 087),[2] as opposed to the 0.37% assumed in the current analysis (based on 22 cases of nonischemic troponin elevation in 6021 Canadian patients); therefore, we also ran a sensitivity analysis imputing 0.59% false-positive in the monitoring alternative.

To assess the cost-effectiveness of troponin T monitoring in populations at various levels of risk for MINS, we analyzed the following subgroups: 1) age 65 years or more, 2) urgent/emergent surgery, 3) history of coronary artery disease and 4) age 65 years or more, or history of coronary artery disease, peripheral vascular disease, cerebrovascular event or diabetes.

Patients experience MINS at different times after the procedure. Therefore, varying timelines after the procedure and increasing numbers of troponin T measurements will detect events that had not yet occurred at the time of

the previous measurement. This represents a major difference from screening programs for static disease (e.g., cancer), where a marginal approach is used for increasing the number of tests. To assess the impact of using different monitoring strategies, we estimated the cost and number of cases of MINS detected using monitoring based on 1) a single troponin T measurement 6–12 hours postoperatively, 2) measurements 6–12 hours postoperatively and on postoperative day 1, 3) measurements 6–12 hours postoperatively and on postoperative days 1 and 2, and 4) measurement only on postoperative days 1 and 2. In the base case, the troponin T level was measured 6–12 hours postoperatively and daily up to the third postoperative day (VISION study protocol).

Table 1. Parameters and their distributions of the model of troponin T monitoring on the detection of myocardial injury after noncardiac surgery

Parameter	Point estimate	Distribution	α/β or SE	Source
Health state				
True-negative troponin T monitoring	91.18%	b	5490/531	VISION study[2]
True-positive troponin T monitoring	8.39%	b	505/5516	VISION study[2]
False-negative troponin T monitoring	0.07%	b	4/6017	VISION study[2]
False-positive troponin T monitoring	0.37%	b	22/5999	VISION study[2]
True-negative standard care	90.63%	b	5457/564	Residual
True-positive standard care	1.52%	b	91/5920	VISION study[2]†
False-negative standard care	6.94%	b	418/5603	VISION study[2]†
False-positive standard care	0.92%	b	55/5966	Expert-based
Cost parameters*				
Electrocardiography	$11.05	NA	—	Ontario Health Insurance Plan Schedule of Benefits[9]
Echocardiography	$208.80	NA	—	Ontario Health Insurance Plan Schedule of Benefits[9]
Troponin T measurement (per measurement)	$18.00	NA	—	Laboratory Reference Centre affiliated with Hamilton Health Sciences
Cardiologist consultation	$157	NA	—	Ontario Health Insurance Plan Schedule of Benefits[10]
Cardiologist partial assessment	$31	NA	—	Ontario Health Insurance Plan Schedule of Benefits[10]
Coronary angiography	$2903.99	NA	—	Clement et al.,[11] CanadianConsumer Price Index
Probability that troponin T level would exceed upper limit of normal in last scheduled measurement	15.23%	b	46/256	VISION study[2] (patients with all 4 measurements)
Probability of angiography in patients who experience MINS	0.99%	b	5/500	VISION study[2]
Probability of angiography in patients with symptomatic MINS	5.41%	b	4/70	VISION study[2]
Probability of angiography in patients with false-positive troponin T monitoring	4.55%	b	1/21	VISION study[2]
Probability of angiography in patients with false-negative troponin T monitoring	25%	b	1/3	VISION study[2]
Cost of troponin monitoring true-negative	$72.00	Log normal	3.60	Based on predefined diagnostic algorithms (see Methods)
Cost of troponin monitoring true-positive	$597.24	Log normal	27.39	Based on predefined diagnostic algorithms (see Methods)
Cost of troponin monitoring false-negative	$1276.32	Log normal	41.73	Based on predefined diagnostic algorithms (see Methods)
Cost of troponin monitoring false-positive	$605.75	Log normal	18.44	Based on predefined diagnostic algorithms (see Methods)
Cost of standard care true-negative	$0.00	NA	—	Based on predefined diagnostic algorithms (see Methods)
Cost of standard care true-positive	$734.27	Log normal	29.27	Based on predefined diagnostic algorithms (see Methods)
Cost of standard care false-negative	$0.00	NA	—	Based on predefined diagnostic algorithms (see Methods)
Cost of standard care false-positive	$58.10	Log normal	3.47	Based on predefined diagnostic algorithms (see Methods)

MINS = myocardial injury after noncardiac surgery; NA = not applicable; SE = standard error; VISION = Vascular Events in Noncardiac Surgery Patients Cohort Evaluation.

*In 2015 Canadian dollars.

†Proportion of cases of ischemic troponin T elevation; i.e., including false-negative troponin T monitoring.

Results

Just less than half of the 6021 Canadian VISION study patients were men (2886 [47.9%]) and were aged 65 years or more (2975 [49.4%]). Table 2 shows the patients' demographic characteristics, preoperative risk factors, type of surgery.

Reference model

Table 3 summarizes the resources used in the various health states according to the diagnostic algorithms. The unit costs and their sources are shown in Table 2.

The incremental cost of a monitoring program consisting of 4 troponin T measurements was $112.18 per screened patient, including follow-up diagnostic tests and consultations in patients with elevated troponin T levels (Table 4). The incremental cost per additional case of MINS detected was $1632.51. The distribution of the simulations in the incremental cost-effectiveness plan is shown in supplementary Fig. S1, Appendix 1 (available at canjsurg.ca/010217-a1). Under the assumption of 500 000 noncardiac surgical procedures per year in Canada,[1] the annual cost of a MINS monitoring program would amount to $56.1 million, with the incremental detection of 34 354 MINS events. The absolute 30-day mortality rate among patients with MINS was 9.6% (95% confidence interval 8.0–11.4).[2]

Sensitivity and scenario analyses

The incremental cost to detect an additional case of MINS rose to $2138 under the worst-case scenario and was $1134 in the best-case scenario. Table 5 shows the results of other sensitivity analyses.

The incremental cost per additional case detected was lower in patients at higher risk for MINS (Table 6; Supplementary Fig. 2, Appendix 1).

Myocardial injury after noncardiac surgery occurred in 34.6% of patients within the first 6–12 hours after surgery, in 22.9% on the first postoperative day, in 26% on the

Table 2. Baseline characteristics overall and by health state at the end of the monitoring period of Canadian VISION patients[2]

	Health state; no. (%) of patients*				
Characteristic	All *n* = 6021	True-negative troponin T monitoring *n* = 5490	True-positive troponin monitoring *n* = 505	False-negative troponin T monitoring *n* = 4	False-positive troponin T monitoring *n* = 22
Age, mean ± SD; yr	65 ± 12	64 ± 11	72 ± 12	74 ± 7	73 ± 10
Age ≥ 65 yr	2975 (49.4)	2593 (47.2)	359 (71.1)	4 (100)	19 (86)
Age ≥ 75 yr	1415 (23.5)	1154 (21.0)	248 (49.1)	2 (50)	11 (50)
Male sex	2886 (47.9)	2583 (47.0)	288 (57.0)	3 (75)	12 (54)
History of congestive heart failure	191 (3.2)	135 (2.4)	52 (10.3)	0 (0)	4 (18)
History of coronary artery disease	1005 (16.7)	814 (14.8)	184 (36.4)	2 (50)	5 (23)
Current atrial fibrillation	192 (3.2)	147 (2.7)	39 (7.7)	0 (0)	6 (27)
History of cerebrovascular event	428 (7.1)	345 (6.3)	77 (15.2)	0 (0)	6 (27)
History of peripheral vascular disease	292 (4.8)	211 (3.8)	75 (14.8)	1 (25)	5 (23)
History of hypertension	3241 (53.8)	2851 (51.9)	368 (72.9)	4 (100)	18 (82)
History of diabetes	1119 (18.6)	951 (17.3)	158 (31.3)	1 (25)	9 (41)
Urgent/emergent surgery†	607 (10.1)	514 (9.4)	87 (17.2)	1 (25)	5 (23)
Vascular surgery‡	240 (4.0)	196 (3.6)	43 (8.5)	0 (0)	1 (4)
General surgery§	1006 (16.7)	897 (16.3)	100 (19.8)	2 (50)	7 (32)
Major urogynecologic surgery¶	745 (12.4)	677 (12.3)	66 (13.1)	0 (0)	2 (9)
Major orthopedic surgery**	1649 (27.4)	1481 (27.0)	161 (31.9)	2 (50)	5 (23)
Neurosurgery††	386 (6.4)	362 (6.6)	24 (4.8)	0 (0)	0 (0)
Low-risk surgery‡‡	1924 (32.0)	1809 (33.0)	109 (21.6)	0 (0)	6 (27)

SD = standard deviation; VISION = Vascular Events in Noncardiac Surgery Patients Cohort Evaluation.

*Except where noted otherwise.

†Procedure performed within 72 hours of the surgery-triggering acute event.

‡Included thoracic aorta or aortoiliac reconstructive procedures, peripheral vascular reconstruction without aortic cross-clamping, extracranial cerebrovascular surgery and endovascular abdominal aortic aneurysm repair.

§Included complex visceral resection, partial or total colectomy or stomach surgery, other intra-abdominal surgery, and major head and neck resection for tumour.

¶Included visceral resection (e.g., nephrectomy, ureterectomy, bladder resection, retroperitoneal tumour resection, radical procedure for cancer [i.e., exenteration], hysterectomy).

**Included major hip or pelvis surgery (hemi or total hip arthroplasty, internal fixation of hip, pelvic arthroplasty).

††Included craniotomy and spine surgery involving multiple levels of the spine.

‡‡Included parathyroid, thyroid, breast, hernia or local anorectal procedure, radical prostatectomy, transurethral prostatectomy, oopherectomy, salpingectomy, endometrial ablation, peripheral nerve surgery, ear/nose/throat surgery, vertebral disc surgery, spinal fusion, knee arthroplasty, hand surgery, cosmetic surgery, arteriovenous access surgery for dialysis, other surgery not fulfilling the major criteria as above.

Table 3. Resource use according to predefined diagnostic algorithms by health state

Health state	Resource; no. of uses						
	Cardiologist consultation	Cardiologist partial assessment	Electrocardiography	Echocardiography	Scheduled troponin T measurement	Triggered troponin T measurement	Angiography
True-negative troponin T monitoring	0	0	0	0	4	0	0
True-positive troponin T monitoring	1	3	4	1	4	1 × probability of first elevation of troponin T level occurring on postoperative day 3*	1 × probability of angiography after MINS
False-negative troponin T monitoring	1	3	2	1	4	1	1 × probability of angiography in false-negative troponin T monitoring
False-positive troponin T monitoring	1	0	4	1	4	1 × probability of first elevation of troponin T level occurring on postoperative day 3*	1 × probability of angiography in false-positive troponin T monitoring
True-negative standard care	0	0	0	0	0	0	0
True-positive standard care	1	3	4	1	0	2	1 × probability of angiography after symptomatic MINS
False-negative standard care	0	0	0	0	0	0	0
False-positive standard care	0	0	2	0	0	2	0

MINS = myocardial injury after noncardiac surgery.
*Last day of scheduled troponin T measurement.

Table 4. Cost and number of detected cases of myocardial injury after noncardiac surgery with troponin T monitoring and with standard care

Variable	Troponin T monitoring	Standard care	Incremental cost, $*	Incremental cost per additional case of MINS detected*
Cost, $	123.87	11.70	112.18	1632.51
No. of cases of MINS detected	0.084	0.015	0.069	—

MINS = myocardial injury after noncardiac surgery.
*2015 Canadian dollars.

Table 5. Scenario analyses assessing the impact of varying costs and false-positive rates in the standard care alternative on the cost-effectiveness estimates

Variable	Incremental cost per patient screened, $*	Incremental cost per additional case of MINS detected, $*
Reference case	112.18	1632.51
25% cost increase in monitoring and 25% cost reduction in standard care alternative (worst case)	146.81	2137.70
25% cost reduction in monitoring and 25% cost increase in standard care alternative (best case)	77.88	1134.28
50% of patients with elevated troponin T levels undergo echocardiography	102.74	1495.28
75% of patients with elevated troponin T levels undergo echocardiography	107.38	1564.85
0% false-positive in standard care	112.58	1639.39
0.59% false-positive with monitoring	113.58	1650.16

MINS = myocardial injury after noncardiac surgery.
*2015 Canadian dollars.

Table 6. Cost-effectiveness ratio, cost and incremental number of myocardial injury after noncardiac surgery events detected in populations at various risk

Population	Incremental cost per case of MINS detected, $*	Annual volume	Cost, $ millions*	No. of incremental cases of MINS detected
Age ≥ 45 yr	1633	500 000	56.1	34 354
Age ≥ 65 yr	1337	247 000	31.7	23 753
History of coronary artery disease	1084	83 500	12.3	11 359
Urgent/emergent surgery	1192	50 500	7.3	6087
Age ≥ 65 yr or history of coronary artery disease, peripheral vascular disease, cerebrovascular event or diabetes	1309	280 500	36.9	28 171

MINS = myocardial injury after noncardiac surgery.
*2015 Canadian dollars.

Table 7. Cost-effectiveness ratio, cost and incremental number of myocardial injury after noncardiac surgery events detected with various troponin T monitoring alternatives

Timing of troponin T measurement	Incremental cost per case of MINS detected, $*	Cost, $ millions*	No. of incremental cases of MINS detected
6–12 h postoperatively and postoperative days 1, 2 and 3	1633.00	56.1	34 354
6–12 h postoperatively	14 248.00	46.8	3283
6–12 h postoperatively and postoperative day 1	4429.00	51.0	11 518
6–12 h postoperatively and postoperative days 1 and 2	2599.55	52.8	20 313

MINS = myocardial injury after noncardiac surgery.
*2015 Canadian dollars.

second postoperative day and in 16.5% on the third postoperative day. A monitoring protocol that measured the troponin T level 6–12 hours after surgery and daily on postoperative days 1, 2 and 3 resulted in the lowest incremental costs for detected MINS (Table 7).

Discussion

This analysis suggests that the incremental cost to avoid missing a MINS event through troponin T monitoring after noncardiac surgery in unselected patients aged 45 years or more would be less than $1650. The estimated incremental cost to detect an additional case of MINS was less than $1350 in selected populations (e.g., patients aged ≥ 65 yr, those undergoing urgent/emergent surgery and those with a history of cardiovascular disease).

Among the screening protocols tested, monitoring consisting of troponin T measurements 6–12 hours after surgery and on postoperative days 1, 2, and 3 resulted in the lowest incremental costs per case of MINS detected. Under the assumption of an annual surgical volume of 500 000 inpatient noncardiac surgical procedures in Canada,[1] a budget of around $56 million would allow physicians to identify over 34 000 additional MINS cases.

Mantha and colleagues[13] evaluated the cost-effectiveness of a postoperative troponin T monitoring strategy to initiate heart rate control and surveillance in a coronary care unit after abdominal aortic aneurysm repair. They populated their model based on data from the literature and assumed a hypothetical relative risk of 0.55 for myocardial ischemia using the strategies mentioned. They concluded that troponin T monitoring after abdominal aortic aneurysm repair was cost-effective (US$12 641 per quality-adjusted life-year [QALY]).

Torborg and colleagues[14] conducted an economic analysis of perioperative troponin monitoring after noncardiac surgery in South Africa. They assumed a 25% reduction in 30-day rates of cardiovascular mortality and myocardial infarction after initiation of treatment with acetylsalicylic acid and statins in patients with positive screening results. The monitoring alternative dominated standard care, i.e., it prevented 30-day adverse events at lower cost.

Our model was populated by a large cohort of patients undergoing a broad spectrum of noncardiac surgical procedures, and it was limited neither by the use of QALY not specific for postoperative events nor by assumptions of a hypothetical treatment effect. In spite of these differences in methods, all evaluations suggest that there may be health gains achievable by troponin T monitoring after noncardiac surgery within commonly applied ceiling ratios.

Strengths and limitations

Our study's strengths include the large, representative, contemporary sample of patients (> 6000, broad inclusion criteria) undergoing noncardiac surgery in Canada. In addition to assessing the cost per additional case of MINS detected, we also assessed affordability (i.e., the cost associated with a troponin T monitoring program).[15] Finally, the results are not limited by extensive assumptions regarding monitoring and treatment effect or by long-term extrapolations; rather, they rely closely on the observed data.

This cost–consequence analysis has limitations. The VISION study did not collect data on resource use. To estimate resource use in the presence of elevated troponin T levels, we applied diagnostic algorithms both for troponin T monitoring and for standard care, based on expert opinion that was not generated in a Delphi panel. We addressed this limitation by conducting scenario analyses that varied the cost of the monitoring and standard-care alternatives: even in the worst-case scenario, the incremental cost to detect an additional case of MINS remained moderate (< $2200).

Furthermore, given that the VISION study did not have a standard-care alternative, the model relied on the following assumptions with regard to the health states. First, we assumed that the proportion of MINS cases detected and missed by clinical assessment corresponded to the symptomatic and asymptomatic cases, respectively, of MINS. Second, because ischemic symptoms in patients with normal troponin T levels were not collected in the VISION study, we estimated the proportion of false-positive findings (i.e., noncardiac chest pain) with standard care based on expert opinion. However, our sensitivity analyses suggest a limited impact of this parameter, and we opted for a conservative estimate of false-positive findings in the standard care alternative. As such, the results presented here underestimate the actual cost of standard care. In other words, the model overestimated the cost of troponin T monitoring after noncardiac surgery.

The source for estimation of coronary angiogram cost included both in-hospital and outpatient angiography. The model did not take into account whether coronary angiography in patients with MINS was performed during the hospital stay for noncardiac surgery or after discharge (plausible in the case of asymptomatic patients). However, coronary angiography was done in less than 1% of patients with MINS; as such, the impact on the overall cost of troponin T monitoring was minor. Furthermore, because more cases of MINS were detected with the troponin T monitoring alternative than with standard care, any potential impact of uncertainty with regard to angiography cost would have led to overestimation of the cost of troponin T monitoring.

Finally, the VISION study measured troponin T in all patients; thus, it did not provide estimates of the effect of troponin T monitoring on outcomes. There is no evidence from randomized controlled trials of the effectiveness of troponin T monitoring after noncardiac surgery on outcomes important to patients, and the optimal treatment of MINS has not been established. Therefore, we opted for a cost–consequence analysis with detected MINS as the health consequence of interest rather than assuming a treatment effect to estimate gain in survival or QALYs. However, this fact can also be considered as a strength because the model did not require extended assumptions or extrapolations. Furthermore, modelling guidelines[12,16] agree that lack of data — in this case, evidence from randomized controlled trials to establish treatment for MINS — should not prevent economic evaluations.[16] A large randomized trial examining MINS treatment has recently been completed.[17]

Conclusion

More than 500 000 Canadians undergo inpatient noncardiac surgery annually, and around 40 000 patients will experience MINS, a condition strongly associated with 30-day mortality. The condition remains undetected in more than 4 in 5 patients (i.e., about 34 000 patients yearly in Canada) because of the lack of ischemic symptoms. Based on the estimated incremental cost per health gain, the implementation of a troponin T monitoring program after noncardiac surgery seems appealing.

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Funding: Canadian Institutes of Health Research (6 grants) (Ottawa, Ontario, Canada); Heart and Stroke Foundation of Ontario (2 grants) (Toronto, Ontario, Canada); Academic Health Science Centre Alternative Funding Plan Innovation Fund grant (Toronto, Ontario, Canada); Population Health Research Institute grant (Hamilton, Ontario, Canada); Clarity Research Group grant; Surgical Associates Research Grant, Department of Surgery, McMaster University (Hamilton, Ontario,

Canada); Hamilton Health Sciences New Investigator Fund grant (Hamilton, Ontario, Canada); Hamilton Health Sciences grant (Hamilton, Ontario, Canada); Ontario Ministry of Resource and Innovation grant (Toronto, Ontario, Canada); Stryker Canada (Waterdown, Ontario, Canada); Department of Anesthesia, McMaster University (2 grants) (Hamilton, Ontario, Canada); Department of Medicine, Saint Joseph's Healthcare (2 grants) (Hamilton, Ontario, Canada); Father Sean O'Sullivan Research Centre (2 grants) (Hamilton, Ontario, Canada); Department of Medicine, McMaster University (2 grants) (Hamilton, Ontario, Canada); Roche Diagnostics Global Office (3 grants) (Basel, Switzerland); Hamilton Health Sciences Summer Studentships (6 grants) (Hamilton, Ontario, Canada); Department of Clinical Epidemiology and Biostatistics (now Health Research Methods, Evidence, and Impact) grant, McMaster University (Hamilton, Ontario, Canada); Division of Cardiology grant, McMaster University (Hamilton, Ontario, Canada); Canadian Network and Centre for Trials Internationally grant (Hamilton, Ontario, Canada); Winnipeg Health Sciences Foundation Operating Grant (Winnipeg, Manitoba, Canada); Department of Surgery Research Grant, University of Manitoba (2 grants) (Winnipeg, Manitoba, Canada); Diagnostic Services of Manitoba Research Grant (2 grants) (Winnipeg, Manitoba, Canada); Manitoba Medical Services Foundation grant (Winnipeg, Manitoba, Canada); Manitoba Health Research Council grant (Winnipeg, Manitoba, Canada); Faculty of Dentistry Operational Fund grant, University of Manitoba (Winnipeg, Manitoba, Canada); Department of Anesthesia (now Department of Anesthesia and Perioperative Medicine) grant, University of Manitoba (Winnipeg, Manitoba, Canada); University Medical Group Start-up Fund, Department of Surgery, University of Manitoba (Winnipeg, Manitoba, Canada), Fellowship for prospective researchers, Swiss National Science Foundation (Bern, Switzerland)

Competing interests: Roche Diagnostics provided the troponin T assays and financial support for the VISION study. P. Devereaux has received other funding from Roche Diagnostics and Abbott Diagnostics for investigator-initiated studies. No other competing interests declared.

Contributors: G. Lurati Buse, A. Lamy, G. Guyatt, C. Polanczyk, O. Berwanger, V. Abraham, Y. Le Manach and P. Devereaux designed the study. G. Lurati Buse, C. Polanczyk, M. Chan, C.Y. Wang, J. Villar, A. Sigamani, O. Berwanger, B. Biccard, R. Pearse, G. Urrútia, I. Garutti, S. Srinathan, G. Malaga, V. Abraham, M. Jacka, M. Tiboni, G. Ackland, D. Macneil, R. Sapsford and M. Leuwer acquired the data, which G. Lurati Buse, B. Manns, A. Lamy, G. Guyatt, C. Polanczyk, C.Y. Wang, D. Sessler, R.W. Szczeklik, S. Srinathan, G. Malaga, C. Chow, Y. Le Manach and P. Devereaux analyzed. G. Lurati Buse, C. Polanczyk and V. Abraham wrote the article, which all authors reviewed and approved for publication.

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