REPORTS OF ORIGINAL INVESTIGATIONS

Incidence and predictors of myocardial and kidney injury following endovascular aortic repair: a retrospective cohort study

Incidence et prédicteurs de lésion myocardique et rénale après réparation aortique endovasculaire : une étude de cohorte rétrospective

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Abstract

Purpose *We performed a retrospective cohort study in patients who underwent endovascular aneurysm repair (EVAR) to determine the incidence and predictors of myocardial injury and acute kidney injury (AKI).*

Methods *We included 267 consecutive patients who underwent EVAR at two tertiary centres in Canada and Poland. The primary outcome was myocardial injury during hospital stay after EVAR defined as a troponin elevation (ultra-sensitivity troponin I Vidas $\geq$ 19 ng·L^{-1}, non-high-sensitivity troponin I Vidas $\geq$ 0.01 μg·L^{-1}, high-sensitivity troponin T $\geq$ 20 ng·L^{-1}, non-high-sensitivity troponin T $\geq$ 0.03 ng·mL^{-1}). The secondary outcome was AKI defined using the stage 1 of the Acute Kidney Injury Network criteria.*

Results *Myocardial injury occurred in 78/267 patients (29%; 95% confidence interval [CI], 24.1 to 34.9) and with AKI occurring in 25/267 (9.4%; 95% CI, 6.4 to 13.5). In a multivariable analysis, the following variables were associated with an increased risk of myocardial injury: age (adjusted odds ratio [aOR], 1.65 per ten-year increase; 95% CI, 1.09 to 2.49), Revised Cardiac Risk Index score $\geq$3 (aOR, 2.85; 95% CI, 1.26 to 6.41), The American Society of Anesthesiology physical status score 4 (aOR, 2.24; 95% CI, 1.12 to 4.47), duration of surgery (aOR, 1.27 per each hour; 95% CI, 1.00 to 1.61), and perioperative drop in hemoglobin (aOR, 3.35 per 10 g·dL^{-1} decrease; 95% CI, 1.00 to 11.3). Predictors of AKI were duration of surgery (aOR, 1.72 per hour; 95% CI, 1.36 to 2.17), a preoperative estimated glomerular filtration rate (eGFR) of 30-59 mL·min^{-1} (aOR, 3.82; 95% CI, 1.42 to 10.3), and an eGFR < 30 mL·min^{-1} (aOR, 37.0; 95% CI, 7.1 to 193.8).*

Conclusion *Myocardial injury and AKI are frequent during hospital stay after EVAR and warrant further investigation in prospective studies.*

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Résumé

Objectif *Nous avons réalisé une étude de cohorte rétrospective auprès de patients ayant subi une*

réparation d'anévrisme endovasculaire (EVAR) afin de déterminer l'incidence et les prédicteurs de lésion myocardique et d'insuffisance rénale aiguë (IRA).

Méthode *Nous avons inclus 267 patients consécutifs ayant subi une EVAR dans deux centres tertiaires au Canada et en Pologne. Le critère d'évaluation principal était une lésion myocardique survenue pendant le séjour à l'hôpital après une EVAR, définie telle qu'une élévation de la troponine (troponine I à haute sensibilité Vidas ≥ 19 ng·L^{-1}, troponine I Vidas ≥ 0,01 μg·L^{-1}, troponine T à haute sensibilité ≥ 20 ng·L^{-1}, troponine T ≥ 0,03 ng·mL^{-1}). Le critère d'évaluation secondaire était une IRA définie en utilisant le stade 1 des critères du Acute Kidney Injury Network (Réseau d'insuffisance rénale aiguë).*

Résultats *Une lésion myocardique est survenue chez 78/267 patients (29 %; intervalle de confiance [IC] 95 %, 24,1 à 34,9), et une IRA chez 25/267 (9,4 %; IC 95 %, 6,4 à 13,5) patients. Dans une analyse multivariée, les variables suivantes ont été associées à un risque accru de lésion myocardique : l'âge (rapport de cotes ajusté [RCa], 1,65 par augmentation de dix ans; IC 95 %, 1,09 à 2,49), un score sur l'Index révisé de risque cardiaque ≥ 3 (RCa, 2,85; IC 95 %, 1,26 à 6,41), un score de statut physique ASA de 4 (RCa, 2,24; IC 95 %, 1,12 à 4,47), la durée de la chirurgie (RCa, 1,27 par heure; IC 95 %, 1,00 à 1,61), et une baisse périopératoire de l'hémoglobine (RCa, 3,35 par réduction de 10 g·dL^{-1}; IC 95 %, 1,00 à 11,3). Les prédicteurs d'IRA étaient la durée de la chirurgie (RCa, 1,72 par heure; IC 95 %, 1,36 à 2,17), un taux préopératoire de filtration glomérulaire estimé (eGFR) de 30-59 mL·min^{-1} (RCa, 3,82; IC 95 %, 1,42 à 10,3), et un eGFR < 30 mL·min^{-1} (RCa, 37,0; IC 95 %, 7,1 à 193,8).*

Conclusion *Les lésions myocardiques et les IRA sont fréquentes pendant le séjour hospitalier après une EVAR; des recherches supplémentaires sous forme d'études prospectives sont nécessaires.*

Abdominal aortic aneurysms (AAAs) are the most common arterial aneurysms occurring in the elderly population. Complications related to AAAs were the underlying cause of almost 10,000 deaths in the United States in 2016 and are ranked by the Centre for Disease Control as one of the top 15 causes of mortality in adults aged ≥ 65 yr.[1-4] Endovascular aneurysm repair (EVAR) is the current intervention of choice for the management of infrarenal aortic aneurysms because of improved short-term morbidity and mortality outcomes compared with open surgical repair, particularly in high-risk patients with multiple comorbidities.[1,3,5,6] Despite technological advances in stent design and implantation, EVAR is still considered an intermediate- to high-risk procedure in terms of cardiovascular and renal complications.[1,3,6,7]

Perioperative myocardial injury and acute kidney injury (AKI) are both independently associated with higher morbidity, 30-day mortality, and prolonged length of hospital stay in patients following noncardiac and vascular surgery.[6,8-13] Recent reports revealed that myocardial injury after vascular surgery can affect between 19 and 25% of patients, while AKI can develop in up to 19% of those who underwent endovascular aortic repair.[10,13-16] The majority of patients with postoperative myocardial injury and AKI do not experience clinical ischemic symptoms; therefore, in the absence of routine postoperative troponin and creatinine surveillance, myocardial and kidney injuries are frequently missed in clinical practice.[10,17,18]

Considering the importance of postoperative acute renal and myocardial injuries and the limited evidence regarding these events in EVAR patients, we undertook this study to determine the incidence and predictors of postoperative AKI and myocardial injury in this population.

Methods

We performed a retrospective cohort study using a convenient sample of consecutive patients who underwent EVAR surgery at two tertiary reference centres in Canada and Poland. Patients aged 18 yr or older undergoing EVAR were considered eligible for the study. Study personnel extracted data from hospital charts and entered these data in case report forms. Baseline characteristics, medications, duration of surgery, preoperative and postoperative hemoglobin and creatinine levels, as well as postoperative outcomes were collected up until patient's hospital discharge following the index EVAR intervention. Screening for myocardial injury was performed routinely in every patient after the procedure as per standard of care at participating centres; troponin level was measured at least once in the first three postoperative days. Local Research Ethics Board (REB) approvals were obtained (October 5, 2012 at the Canadian centre and December 27, 2016 at the Polish centre) before data were extracted. Individual patient consent was not obtained as it was not required by local REBs.

The primary outcome was myocardial injury occurring after an EVAR procedure and up to hospital discharge. Myocardial injury was defined as a troponin elevation above the 99th percentile upper reference limit for troponin I, and where troponin T was measured, we used the thresholds established in the VISION studies.[12,19] Definitions and cutoff used for each type of troponin are

reported in the eAppendix (available as Electronic Supplementary Material [ESM]). A high and ultra-sensitivity troponin assay was used in 140 (52.5%) of eligible patients. The secondary outcome was AKI during hospital stay after surgery and was defined using the stage 1 of the Acute Kidney Injury Network (AKIN) criteria (i.e., increase of creatinine serum concentration ≥ 27 μmol·L^{-1} or ≥ 1.5-fold increase in serum creatinine compared with baseline level) during the post-surgery hospital stay.[20]
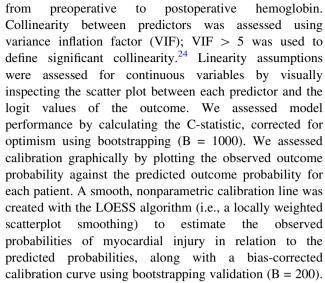
The Revised Cardiac Risk Index (RCRI) was calculated for all patients (i.e., one point for each of the following: history of ischemic heart disease, congestive heart failure, cerebrovascular disease, preoperative insulin therapy, preoperative serum creatinine concentration > 176.8 μmol·L^{-1}, and high-risk surgery).[21] The American Society of Anesthesiology (ASA) physical status score was determined by the attending anesthesiologist, according to current guidelines.[22]

During the hospitalization period, the following complications were also recorded: new episode of atrial fibrillation, stroke/transient ischemic attack (TIA), acute congestive heart failure, and all-cause mortality. Stroke/TIA was defined as a new focal neurologic deficit thought to be vascular in origin. Acute congestive heart failure was diagnosed if one of the new clinical and radiographic findings were present: elevated jugular venous pressure, respiratory rales/crackles, crepitations, vascular redistribution, interstitial pulmonary edema, or frank alveolar pulmonary edema. For patients with an elevated troponin, study personnel looked for evidence of symptoms and electrocardiogram (ECG) changes reported by the internist or in cardiologist consultation reports and from electronic health records from the day of myocardial injury diagnosis. The Third Universal Definition of Myocardial Infarction was used to diagnose myocardial infarction.[23]

Statistical analysis

Patient characteristics were reported using absolute numbers and percentages with corresponding 95% confidence intervals (CI), mean (standard deviation), or median [interquartile range (IQR)], whenever appropriate.

We used a semi-parsimonious approach to develop a model to predict myocardial injury using multivariable logistic regression. We expected an approximate 30% myocardial injury event rate in this vascular surgery population, which should relate to 90 events and allow for adjusted analysis with nine to ten predictors. Variables to include in the multivariable prediction model were defined *a priori* based on background knowledge and literature review.[7,16,19] We included the following variables in the multivariable model: age, sex, RCRI score, duration of surgery, ASA physical status, and change

from preoperative to postoperative hemoglobin. Collinearity between predictors was assessed using variance inflation factor (VIF); VIF > 5 was used to define significant collinearity.[24] Linearity assumptions were assessed for continuous variables by visually inspecting the scatter plot between each predictor and the logit values of the outcome. We assessed model performance by calculating the C-statistic, corrected for optimism using bootstrapping (B = 1000). We assessed calibration graphically by plotting the observed outcome probability against the predicted outcome probability for each patient. A smooth, nonparametric calibration line was created with the LOESS algorithm (i.e., a locally weighted scatterplot smoothing) to estimate the observed probabilities of myocardial injury in relation to the predicted probabilities, along with a bias-corrected calibration curve using bootstrapping validation (B = 200).

For AKI up to hospital discharge, we used a similar approach as detailed above for myocardial injury. In multivariable analysis, we planned to adjust for the following predefined risk factors: age, coronary artery disease, duration of surgery, preoperative estimated glomerular filtration rate (eGFR), and change from preoperative to postoperative hemoglobin. Missing covariate data were imputed using the mean or median. Patients with missing outcome data were assumed to not have suffered the event and the impact of the missing data were assessed in sensitivity analysis using the missing-indicator method and complete case analysis. Statistical significance was considered at $P < 0.05$ for all analyses. A sample size estimation was not performed prior to data collection. The analyses were performed using IBM SPSS Statistics 25 and R version 3.5.0 (The R Foundation for Statistical Computing).

Results

A total of 267 patients who underwent EVAR were enrolled (170 from Poland and 97 from Canada). Patients baseline characteristics including perioperative data are shown in Table 1. The participants were predominantly elderly males (86.5%), and commonly had a history of smoking (77.9%), coronary artery disease (60.3%), and congestive heart failure (30.0%).

Overall, the most common cardiovascular complication was myocardial injury (78/267; 29.2%; 95% CI, 24.1 to 34.9) (Table 2) of which 18/78 (23.1%) met the Universal Definition of Myocardial Infarction.[23] Acute kidney injury occurred in 9.4% (25/267; 95% CI, 6.4 to 13.5) of patients. No patient required new renal replacement therapy (i.e., dialysis) after their EVAR procedure. Other postoperative cardiovascular events included new atrial fibrillation

Table 1 Baseline characteristics of patients with and without myocardial injury and acute kidney injury during hospital stay after EVAR

	All n = 267	No myocardial injury n = 189	Myocardial injury n = 78	No AKI n = 242	AKI n = 25
Demographic					
Age (yr), mean (SD)	75.8 (7.7)	74.9 (7.8)	77.8 (7.1)*	75.5 (7.7)	78.3 (7.0)
Male	231 (86.5)	165 (87.3)	66 (84.6)	212 (87.6)	25 (76.0)
Comorbidities					
CAD	161 (60.3)	107 (56.6)	54 (69.2)	144 (59.5)	17 (68.0)
CHF	80 (30.0)	44 (23.3)	36 (46.2)*	73 (30.2)	7 (28.0)
CVD	34 (12.7)	20 (10.6)	14 (17.9)	31 (12.8)	3 (12.0)
Diabetes	68 (25.5)	50 (26.5)	18 (23.1)	61 (25.2)	7 (28.0)
eGFR < 60 mL·min^{-1}	86 (32.2)	51 (27.0)	35 (45.5)*	72 (29.9)	14 (56.0)*
Smoking history†	208 (77.9)	153 (82.7)	55 (75.3)	187 (79.6)	21 (91.3)
COPD	60 (22.5)	36 (19.0)	24 (30.8)*	58 (24.0)	2 (8.0)
Preoperative medications					
Aspirin	202 (75.7)	149 (78.8)	53 (68.8)	184 (76.3)	18 (72.0)
Clopidogrel	20 (7.5)	14 (7.4)	6 (7.8)	17 (7.1)	3 (12.0)
Statin	213 (79.8)	154 (81.5)	59 (76.6)	194 (80.5)	19 (76.0)
Beta-blocker	185 (69.3)	128 (67.7)	57 (74.0)	165 (68.5)	20 (80.0)
ACEI/ARB	181 (67.8)	134 (70.9)	47 (61.0)	165 (68.5)	16 (64.0)
CCB	87 (32.6)	64 (33.9)	23 (29.9)	76 (31.5)	11 (44.0)
Diuretic anticoagulant	134 (50.2)	89 (47.1)	45 (58.4)	120 (49.8)	14 (56.0)
	12 (4.5)	10 (5.3)	2 (2.6)	11 (4.6)	1 (4.0)
Scales scores					
RCRI score					
1	86 (32.2)	71 (37.6)	15 (19.2)*	81 (33.5)	5 (20.0)
2	87 (32.6)	64 (34.4)	23 (29.5)*	77 (31.8)	11 (44.0)
≥ 3	93 (34.8)	53 (28.0)	40 (51.3)*	84 (34.7)	9 (36.0)
ASA-PS = IV	63 (23.6)	34 (18.0)	29 (37.2)*	59 (23.7)	4 (22.2)
Perioperative characteristics					
Length of surgery (min), median [IQR]	145 [115-180]	145 [120-180]	138 [110-185]	140 [115-180]	180 [150-270]
Length of hospital stay (days), median [IQR]	6 [4-11]	5 [4-9]	8 [4-15]	5 [4-10]	11 [7-17]
Hemoglobin drop ≥ 10 g·L^{-1}‡	12 (4.5)	2 (1.1)	3 (4.2)	5 (2.2)	0 (0.0)
≥1 unit RBC transfused during surgery	30 (11.2)	16 (8.8)	14 (18.4)*	24 (10.3)	6 (24.0)*

Data are presented as n (%) unless otherwise indicated

ACEI = angiotensin-converting enzyme inhibitor; AKI = acute kidney injury; ARB = angiotensin-receptor blocker; ASA-PS = American Society of Anesthesiologists physical status; CAD = coronary artery disease; CCB = calcium channel blocker; CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; CVD = cerebrovascular disease; eGFR = estimated glomerular filtration; EVAR = endovascular aneurysm repair; IQR = interquartile range; RBC = red blood cells; RCRI = Revised Cardiac Risk Index; SD = standard deviation

*Denotes statistically significant difference between groups with and without event ($P < 0.05$)

†Nine missing values

‡12 missing postoperative hemoglobin values

(4.5%; 95% CI, 2.6 to 7.7), acute congestive heart failure (6.0%; 95% CI, 3.7 to 9.5), and stroke/TIA (0.7%; 95% CI, 0.2 to 2.7). The in-hospital mortality rate was 2.6% (95% CI, 1.3 to 5.3).

Myocardial injury

The majority of patients (60/78, 76.9%) with myocardial injury did not experience ischemic symptoms or significant ECG changes. A high- or ultra-sensitivity troponin assay was used in 136/267 (50.9%) of eligible patients (see eTable 1 in ESM for incidence of myocardial injury according to type of troponin and participating centres).

Table 2 Outcome events up to hospital discharge following EVAR

Outcome	n = 267 n (%)	95% CI (%)
Myocardial injury*	78 (29.2)	24.1 to 34.9
Myocardial infarction	18 (6.7)	4.3 to 10.4
AKI	25 (9.4)	6.4 to 13.5
New atrial fibrillation	12 (4.5)	2.6 to 7.7
Stroke/TIA	2 (0.7)	0.2 to 2.7
Acute CHF	16 (6.0)	3.7 to 9.5
Death	7 (2.6)	1.3 to 5.3

AKI = acute kidney injury; CHF = congestive heart failure; CI = confidence interval; EVAR = endovascular aneurysm repair; TIA = transient ischemic attack

*Including myocardial infarction diagnosed according to the Third Universal Definition

The incidence of myocardial injury was higher in centres that used high-sensitivity troponin assays compared with centres that used non-high-sensitivity assays (41.9% [57/136] *vs* 16.0% [21/131], respectively; $P < 0.001$). Characteristics of patients with and without myocardial injury are presented in Table 1. Overall, patients who experienced myocardial injury were older, had lower eGFR, higher RCRI and ASA physical status scores, and more often had a history of congestive heart failure and chronic obstructive pulmonary disease (all $P < 0.05$). Also, patients who suffered a myocardial injury required more red blood cell transfusions. Patients with myocardial injury also had a prolonged median [IQR] length of hospital stay than patients without myocardial injury (8 [4-15] days *vs* 5 [4-9] days, respectively; $P < 0.001$). In multivariate analysis, age, RCRI score ≥ 3, ASA physical status IV, duration of surgery, and perioperative drop in hemoglobin significantly increased the risk of myocardial injury (Table 3). The model performance determined by calculating the C-statistic corrected for optimism showed a moderate discrimination (0.68). The eFigure in the ESM

presents the calibration curve (i.e., plot of predicted probabilities and observed probability with LOESS smoothing) and bias-corrected calibration curve; it did not show significant model miscalibration. We performed *post hoc* analysis of predictors of myocardial injury that included only preoperative predictors (as suggested during peer review), which showed similar results except for the ASA physical status, which was no longer statistically significant (see eTable 2 in the ESM).

Acute kidney injury

Characteristics of patients who developed AKI compared with characteristics of patients without AKI are presented in Table 1. The majority of patients with postoperative AKI (24/25, 96%) met the stage 1 AKIN criteria (i.e., increase in serum creatinine $\geq$ 27 μmol·L-1 or $\geq$ 1.5-fold compared with baseline level) and 4% (1/25) met the stage 3 AKIN criterion for AKI (i.e., increase in serum creatinine > three-fold compared with baseline level). In general, patients who developed AKI had lower preoperative eGFR,

Table 3 Predictors of myocardial injury during hospital stay after EVAR in the multivariable model

	aOR (95% CI)	P value
Age, per ten-year increase	1.65 (1.09 to 2.49)	0.02
RCRI		0.04
1	-	-
2	1.58 (0.71 to 3.51)	-
$\geq$ 3	2.85 (1.26 to 6.4)	
ASA score IV	2.24 (1.12 to 4.47)	0.02
Length of surgery, per 60 min increase	1.27 (1.00 to 1.61)	0.03
Delta hemoglobin, per 10 g·L^{-1} decrease	3.35 (1.00 to 11.3)	0.049

C-statistic 0.70 for myocardial injury model

C-statistic corrected for optimism 0.68

Model developed using complete cases and multivariable logistic regression

aOR = adjusted odds ratio; ASA = American Society of Anesthesiologists; CI = confidence interval; EVAR = endovascular aneurysm repair; RCRI = Revised Cardiac Risk Index

Table 4 Predictors of acute kidney injury during hospital stay after EVAR in the multivariable model

	aOR (95% CI)	*P* value
Preop eGFR		< 0.001
≥ 60	-	-
30-59	3.82 (1.42 to 10.3)	-
< 30	37.0 (7.1 to 193.8)	-
Length of surgery, per 60 min increase	1.72 (1.36 to 2.17)	< 0.001

C-statistic 0.801 for AKI model

C-statistic corrected for optimism 0.791

AKI = acute kidney injury; aOR = adjusted odds ratio; CI = confidence interval; eGFR = estimated glomerular filtration rate; EVAR = endovascular aneurysm repair

a longer duration of surgery and received more units of red blood cells (all $P < 0.05$). Patients who suffered a postoperative AKI had a significantly longer median [IQR] hospital stay than patients without AKI did (11 [7-17] days *vs* 5 [4-10] days, respectively; $P = 0.01$). In multivariate analysis, length of surgery and preoperative eGFR were associated with AKI occurrence (Table 4). The model performance was good, as estimated by the C-statistic corrected for optimism (0.79).

In 60 patients, postoperative creatinine was not measured up to discharge. We used the missing-indicator method to determine the impact of missing data on the association between the predictors and AKI. Adjusting for the missing indicator was not statistically significant ($P = 0.99$) and did not significantly change the point estimate and statistical significance of the covariates in the model. We also performed a complete case analysis and the results did not change significantly (see eTable 3 in the ESM).

Discussion

In this study, we determined the incidence and predictors of myocardial and renal injury in patients who underwent EVAR. We found that myocardial injury was common after EVAR, and that the majority of patients were asymptomatic. These findings are consistent with recent reports suggesting that arterial complications such as myocardial injury are more common than venous complications in vascular surgery patients and are associated with increased mortality.[15] In a sub-study in vascular surgery patients from the VISION study (a prospective, large, international cohort of adults undergoing in-hospital noncardiac surgery who had troponin measured in the first three postoperative days),[12] Biccard *et al.* found that myocardial injury occurred in 19.1% of patients who underwent vascular surgery and was associated with a 9.5-fold increased risk of mortality at 30 days (OR, 9.5; 95% CI, 3.5 to 26.0).[13] They also found that

74.1% of patients with myocardial injury were asymptomatic. Szczeklik *et al.* also described that myocardial injury is frequent in patients undergoing endovascular revascularization for critical limb ischemia, with a 25.5% incidence of myocardial injury after surgery.[14]

Until now, little was known about the prevalence of myocardial injury in patients undergoing EVAR. In a small cohort study of 30 patients who underwent EVAR and had routine troponin T (TnT) measured 24 hr after their procedure, Davies *et al.* showed that five patients (16%) experienced myocardial injury defined as a significant elevation of TnT levels and only one had chest pain with ischemic ECG changes.[25] In our study, the incidence of myocardial injury was almost twice as high. Also, the prevalence of myocardial infarction diagnosed according to the universal definition (6.7%) was higher in our study compared with previous studies—i.e., 5.1% in the EVAR-2 trial, and 1.1% in a study by Steely *et al.*[26,27] This difference is likely explained by the absence of routine troponin screening in these studies and the use of high-sensitivity troponin in a large proportion of our study population. Our cohort included consecutive patients, which likely included patients at higher risk than those who were included in these randomized-controlled trials. In our cohort, 76.9% of patients with myocardial injury after EVAR were asymptomatic. This is consistent with previous evidence that without systematic troponin monitoring, the majority of myocardial injury following noncardiac surgery would go undetected.[1,2] Considering that myocardial injury surgery significantly increases the risk of 30-day mortality in mixed noncardiac surgery,[2] it is reasonable to believe that the same prognosis applies to patients undergoing EVAR.

The reported incidence of AKI within 30 days or during hospitalization after EVAR varies between studies in the literature, likely because of heterogeneity in the definitions used, and ranges from 3.1% to 18.8%.[16,28-31] Recent studies by two groups led by Saratzis and Pirgakis utilized

the AKIN criteria to define postoperative AKI in patients who underwent EVAR and reported an incidence of 18.8% and 17%, respectively, compared with 9.4% in our cohort.[16,31] Also, in contrast to the findings reported by Saratzis *et al.*, we found that both decreased preoperative eGFR level and length of surgery were independent predictors of AKI.[14] We hypothesize that the lower prevalence of perioperative AKI observed in our study group is likely explained by a difference in baseline characteristics between study cohorts and a larger sample size in our study (i.e., 267 patients in our cohort compared with 149 and 87 patients in cohorts by Saratzis *et al.* and Pirgakis *et al.*, respectively). It is also possible that patients whose postoperative creatinine level was not measured contributed to a lower incidence of AKI, although our sensitivity analyses did not suggest that these variables were missing not at random and that these patients would differ from the rest of the population.

In this retrospective cohort, we found that the median length of stay after EVAR was six days. Our finding differs from more recent clinical practice where patients are discharged home the same day or the day following their EVAR surgery.[32,33] As such, the centres where we performed this retrospective study have now transitioned to discharging patients who underwent uncomplicated EVAR the day after the intervention. This is likely explained by the lower incidence of overt complications and short-term mortality associated with EVARs compared with open repair surgeries.[34] Nevertheless, as shown in our study and previous studies, the majority of patients who suffer a myocardial injury do not experience any symptoms and thus, without routine troponin monitoring, these events would be missed. This is also true for AKI, which in the vast majority of cases is an event that is detected during routine renal function monitoring and is usually not associated with clinical symptoms, except in cases of severe renal failure. More centres are moving to very short hospital stays and outpatient intervention after EVAR, so these prognostically significant events may be missed without routine troponin and creatinine monitoring. There is currently no published study regarding the feasibility of troponin and creatinine monitoring in patients who were discharged home after EVAR and the proportion of events that may go undetected.

Thus, larger prospective studies are needed to establish the incidence and prognostic importance of myocardial and renal injury following EVAR, including in patients discharged home early after their intervention. Early identification of patients who experience a myocardial injury after EVAR surgery can allow clinicians to implement additional monitoring and therapeutic measures.[35-37]

Our study has several limitations. First, it is not standard of care at the participating centres to perform routine troponin measurement before surgery. Thus we could not exclude patients with chronically elevated troponin or utilize the criterion of troponin change (i.e., absolute high-sensitivity TnT change of ≥ 5 ng·L^{-1}) to define myocardial injury in this study.[19] Nevertheless, in studies that have evaluated preoperative troponins, elevated troponins before surgery only accounted for 13.8% of the perioperative elevations. Secondly, because of the retrospective nature of the study, there is also a possibility that certain outcomes were not identified, since the monitoring for such complications was at the discretion of the treating physician. It is also possible that the incidence of myocardial injury was underestimated since different types of troponin assays were used at the centres, including non-high-sensitivity assays. In the first 15,065 noncardiac surgery patients enrolled in the VISION study who had non-high-sensitivity TnT measured in the first three days postoperatively, the incidence of myocardial injury was 8.0%.[11] In the subsequent 21,842 patients who had high-sensitivity TnT measured, the incidence was 17.9%.[19] We saw a similar difference between assay types in our study and a higher incidence overall of myocardial injury (16.3% for non-high-sensitivity assays *vs* 41.9% for high-sensitivity assays). This finding is likely explained by the fact that VISION enrolled mixed noncardiac surgeries, including 35.5% of low-risk surgery, and that vascular surgery patients (including EVAR) are considered at higher risk of perioperative cardiovascular complications. We also found a lower incidence of postoperative AKI than was seen in previous studies. This resulted in a smaller number of events, allowing for inclusion of a lower number of covariates in the multivariable model as preplanned. Fortunately, we only found two variables to be significantly associated with the occurrence of AKI (i.e., preoperative eGFR and length of surgery), avoiding the issue of overfitting by adding too many variables in the model.[38] Since postoperative troponin and creatinine were measured as part of clinical practice, patients may have had a different number of daily measurements, varying between one and several days of measurement. These differences in the number of measurements are unlikely to be at random and rather reflect a difference in postoperative course. It is reasonable to believe that patients with a greater number of measurements had a more prolonged hospital stay and possibly more complications. This may have introduced an outcome detection bias, which is a limitation of retrospective studies, but also reflects variation in clinical practice.

Finally, because of the retrospective nature of our study, we could not show if patients with postoperative AKI during their hospital stay had persistent chronic kidney

dysfunction at long-term follow-up. It is not standard of care at the participating centres (or common clinical practice) to systematically measure creatinine several months after discharge in patients who underwent EVAR. Nevertheless, another retrospective cohort comparing EVAR with aortic open repair showed that a postoperative deterioration in kidney function at 30 days was observed in 13% of patients after EVAR and persisted at long-term follow-up, with a 11% reduction in estimated glomerular function following EVAR at nine years.[30]

Conclusions

Myocardial and renal injury are common complications after EVAR. The majority of these events are asymptomatic and without systematic monitoring would likely go undetected. This is of particular importance since patients are usually discharged early after EVAR, and in some cases on the same day of surgery. The awareness of their independent predictors can facilitate identifying high-risk patients susceptible of experiencing cardiovascular and renal complications, some of which may occur after hospital discharge. Further prospective studies are required to inform on the prediction, identification, and management of cardiovascular and renal complications following EVAR.

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