https://doi.org/10.15360/1813-9779-2024-6-2489



# Post-Discharge Cardiovascular Complications in Noncardiac Surgery: Incidence and Prediction

Dmitrii A. Sokolov[1,2]*, Igor A. Kozlov[3]*

[1] Yaroslavl State Medical University, Ministry of Health of Russia,
5 Revolutionary Str., 150000 Yaroslavl, Russia
[2] Regional Clinical Hospital,
7 Yakovlevskaya Srt., 150062 Yaroslavl, Russia
[3] M. F. Vladimirsky Moscow Regional Research Clinical Institute
61/2 Shchepkin Str., 129110 Moscow, Russia

**For citation:** *Dmitrii A. Sokolov, Igor A. Kozlov.* Post-Discharge Cardiovascular Complications in Noncardiac Surgery: Incidence and Prediction. *Obshchaya Reanimatologiya = General Reanimatology.* 2024; 20 (6): 4–14. https://doi.org/10.15360/1813-9779-2024-6-2489 [In Russ. and Engl.]

***Correspondence to:** Dmitrii A. Sokolov, d_inc@mail.ru; Igor A. Kozlov, iakozlov@mail.ru

## Summary

**The aim of this study** was to assess the incidence of cardiovascular complications (CVC) within 12 months after vascular surgery and to analyze inpatient perioperative examination data to identify potential predictors.

**Materials and Methods.** A prospective cohort study included 103 patients aged 66 years [61–70] who underwent vascular surgery. Clinical outcomes within 12 months after surgery, including CVC and/or other cardiac events (composite outcome) and cardiac death, were assessed by telephone interviews with patients or their relatives. Patient physiological parameters, comorbidities, cardiac risk indices (CRI), platelet-lymphocyte ratio (PLR), concentration of N-terminal pro-B-type natriuretic peptide (NT-proBNP), and other parameters were obtained and analyzed from medical records. Logistic regression and ROC analysis were used to assess the predictive power of the investigated indicators.

**Results.** The composite outcome was recorded in 33 % of cases and cardiac death occurred in 6.8 %. The risk of the composite outcome was associated with ASA class (OR 2.7413; 95 % CI 1.1126–6.7541), whereas the risk of perioperative myocardial infarction or cardiac arrest was associated with CRI (OR 1. 6051; 95 % CI 0.6645–2.0215), American University of Beirut (AUB) CRI (OR 2.1106; 95 % CI 1.0260–4.3414), PLR (1.0120; 95 % CI 1.0018–1.0222), and NT-proBNP concentration during hospitalization. Concurrent congestive heart failure (OR 5.0658; 95 % CI 1.2400–20.6956), revised CRI (OR 2.1024; 95 % CI 1.0572–4.1813), Khoronenko CRI (OR 103.76; 95 % CI 1.8752–5796.55), AUB CRI (OR 3.1902; 95 % CI 1.1040–9.2181), and NT-proBNP concentration all increased the risk of cardiac death. Predischarge NT-proBNP levels > 179 pg/mL (OR 1.0071; 95 % CI 1.0038–1.0104; AUC 0.795) and maximum postoperative NT-proBNP levels were reliable predictors of the composite outcome. The most effective predictor of postoperative mortality was a maximum NT-proBNP concentration > 303 pg/mL after surgery (OR 1.0039; 95 % CI 1.0015–1.0063; AUC 0.836).

**Conclusion.** CVC developed in 33 % of patients within 12 months after vascular surgery, with cardiac death occurring in 6.8 % of cases. An NT-proBNP concentration > 179 pg/mL before hospital discharge or a maximum NT-proBNP concentration > 248 pg/mL in the postoperative period predicted CVC within one year. Postoperative NT-proBNP concentration > 303 pg/mL was a strong predictor of one-year cardiac mortality. Other factors associated with the risk of postoperative CVC did not provide an accurate prognosis.

***Keywords: prognosis of post-discharge complications; cardiovascular complications; non-cardiac surgery; predictors of cardiac complications; cardiac risk indices; natriuretic peptides; NT-proBNP; perioperative complications***

**Conflict of interest.** The authors declare no conflict of interest.

## Introduction

Long-term post-discharge cardiovascular complications (CVCs) after non-cardiac surgery are gaining attention among clinicians worldwide [1–4]. Researchers emphasize their medical and public importance [5, 6] while investigating the structure [3] and pathophysiological mechanisms [2, 3, 7] of these complications. Evidence-based analyses have led to the development of national and international guidelines to reduce the risk of CVCs in noncardiac surgical settings [8–13]. Despite these efforts, post-discharge CVCs remain common and are associated with high mortality rates [3, 14].

Current research focuses on improving the prediction of CVCs using modern diagnostic tools [1] and laboratory tests [4, 15–17]. Attempts have also been made to use cardiac risk indices (CRIs) for this purpose [15]. However, methods for predicting post-hospital CVCs need to be refined to improve prognostic accuracy.

In Russia, clinicians have extensively studied perioperative CVCs [18–24], but there are few publications on post-discharge complications. For example, the multicenter STOPRISK study found that the overall incidence of various CVCs within 30 days after abdominal surgery was about 1.4%, which is

comparable to the rate of intestinal paresis but higher than the prevalence of infectious complications [25, 26]. Our previous study found that in a mixed population of patients with vascular disease and cancer, various cardiac events were observed in 27.7% of cases within 12 months of surgery, of which 2.1% were fatal [27]. However, the prevalence and accurate prediction of post-discharge CVCs in vascular surgery remain poorly understood.

Objective: to assess the incidence of CVCs within 12 months after vascular surgery and to investigate the feasibility of predicting these complications using perioperative inpatient data.

## Materials and Methods

A prospective cohort study was conducted at the Yaroslavl Regional Clinical Hospital, including patients who underwent surgery in the Department of Vascular Surgery between May 1 and November 1, 2021 (approved by the local ethics committee of Yaroslavl State Medical University, protocol No. 50-2021). The sample size was calculated under the assumption of regression analysis using the formula $N > 50 + 8m$, where $m$ represents the number of independent variables [28].

Inclusion criteria:

— Discharge from hospital after elective open vascular surgery performed under general anesthesia.

— Age between 45 and 85 years.

— Written informed consent to participate in the study.

— Availability of a contact telephone number.

— Presence of perioperative cardiac biomarker results documented in the medical record.

Exclusion criteria:

— Documented major surgical complications and/or reoperations during hospitalization.

— Presence of clinically significant valvular heart disease and/or left ventricular ejection fraction (LVEF) < 40%.

— Class III obesity with body mass index (BMI) > 40 kg/m².

— Preoperative elevated serum creatinin (> 120 μmol/L).

— Inability to contact the patient by telephone.

— Patient refusal to participate in the study.

— Lack of information about the patient from available contacts.

The study initially included 146 patients discharged from the hospital. Seventeen patients were excluded for the following reasons: five due to surgical complications, four requiring reoperation, two with aortic stenosis, one with a left ventricular ejection fraction (LVEF) of 37 %, two with a body mass index (BMI) of 41 and 44 kg/m², and three with preoperative hypercreatininemia.

Between May 10 and November 10, 2022, telephone interviews were conducted with 129 potential respondents. However, 21 telephone numbers were unreachable and five individuals declined to participate. Finally, data from 103 respondents (patients or their relatives) were included in the study.

The interviews used a specially designed questionnaire (Table 1) to assess the occurrence of cardiovascular complications and/or other cardiac events within 12 months of surgery. Major adverse cardiovascular and cerebrovascular events (MACCE) were defined as cardiac mortality, myocardial infarction, stroke, or a combination thereof [29, 30]. The presence of one or more cardiovascular complications identified by the questionnaire was classified as a composite outcome.

The primary endpoints of the study were the composite outcome and cardiac mortality.

The following patient data were collected from medical records: sex, age at the time of surgery, functional status according to the American Society of Anesthesiologists (ASA) classification, presence of cardiovascular comorbidities, type of surgical procedure, calculated cardiac risk indices (CRIs), and blood indices. The CRIs analyzed included the Revised Cardiac Risk Index (RCRI) [31], the American College of Surgeons Risk Calculator for Perioperative Myocardial Infarction or Cardiac Arrest (MICA CRI) [32], the CRI developed by V. E. Khoronenko et al. (Khoronenko CRI) [33], and the American University of Beirut Cardiovascular Risk Index (AUB-HAS2 CRI) [34]. Increased cardiovascular risk was defined as RCRI > 2 points, MICA CRI > 1%, Khoronenko CRI > 0.3 units, and AUB-HAS2 CRI > 1 point.

Preoperative complete blood counts were used to calculate platelet to lymphocyte ratio (PLR) and neutrophil to lymphocyte ratio (NLR).

**Table 1. Questionnaire used in the study.**

| № | Question | Answer | Note |
|---|---|---|---|
| 1. | Has the patient survived? | yes/no | If not, what was the cause of death |
| 2. | Did the patient have any cardiovascular disease? | yes/no | If yes, which ones |
| 3. | Was there any progression of cardiovascular disease after surgery? | yes/no | If yes, which ones |
| 4. | Did the patient have a myocardial infarction, development or decompensation of heart failure, stroke, arrhythmia within the last 12 months? | yes/no | If yes, specify |
| 5. | Is the patient taking cardiovascular medications? | yes/no | If yes, which ones |
| 6. | Was dosage adjustment of cardiovascular medications required postoperatively? | yes/no | If yes, which drugs |
| 7. | Were there any hospitalizations for heart disease during the year? | yes/no | If yes, specify the cause of hospitalization |
| 8. | Were there any hospitalizations for cardiac surgery performed during the year? | yes/no | If yes, which ones |

The serum concentration of cardiac-specific troponin I (cTnI) was measured using the «Troponin I – ELISA – BEST» reagent kit (AO Vector-Best, Russia) on a Lazurit automated immunoassay analyzer (Dynex Technologies, USA). A value > 0.2 ng/mL was considered to be significantly above the upper limit of the reference range based on the laboratory standards. The concentration of the inactive fragment of the B-type natriuretic peptide precursor (NT-proBNP) in serum was determined by solid-phase enzyme immunoassay using the NT-proBNP ELISA-BEST reagent kit (AO Vector-Best, Russia) on the same analyzer. The upper reference limit for NT-proBNP was set at 200 pg/mL.

Biomarkers were assessed at three time points: preoperatively ($cTnI_1$, $NT\text{-}proBNP_1$), 24 hours postoperatively ($cTnI_2$, $NT\text{-}proBNP_2$), and on postoperative days 5–7 before discharge ($cTnI_3$, $NT\text{-}proBNP_3$). Peak (maximum) postoperative biomarker levels were recorded as $cTnI_{peak}$ and $NT\text{-}proBNP_{peak}$.

The study included 71 male and 32 female participants aged 47–83 years (median age 66 [61–70] years). Of the participants, 55 (53.4%) were over 65 years of age at the time of surgery. During hospitalization, their physical status and anesthesiological risk level were consistent with ASA class III–IV (median score 3.0 [3.0–4.0]). Cohort characteristics, including comorbidities, surgical procedures, and other relevant parameters, are detailed in Table 2.

Data were processed using the MedCalc statistical software package (version 15.2). The Kolmogorov–Smirnov test was used to assess the data distribution. Results were reported as medians *(Me)* with interquartile ranges *(LQ–UQ)*. Logistic regression was used to assess the effect of independent variables (predictors) on dependent variables (outcomes). The effect was binary encoded. Odds ratios *(OR)*, 95% confidence intervals *(CIs)*, and *P*-values were calculated. Potential predictors included demographic and clinical parameters, cardiac risk indices (CRIs), blood indices, and cardiac biomarkers. Composite outcomes and cardiac mortality were analyzed as dependent variables. Receiver operating characteristic (ROC) analysis was performed to evaluate the discriminative ability of the predictors identified by logistic regression. ROC curve characteristics were assessed by calculating area under the curve (AUC), 95% CI, and *P*-values. Model quality was categorized as follows:

AUC ⩾ 0.9: Excellent
0.89–0.8: Very good
0.79–0.7: Good
0.69–0.6: Moderate
< 0.6: Poor.

Thresholds (cut-offs) for variables were determined based on the Youden index, prioritizing the highest sum of sensitivity and specificity. Additional criteria included sensitivity/specificity approaching 80% and balance of sensitivity and specificity (minimizing the difference). The cut-off that best met these criteria was selected, with 95% CIs calculated for the sensitivity and specificity of the cut-off. Statistical significance was set at $P < 0.05$ using a two-tailed significance level.

**Table 2. Characteristics of the patient cohort.**

| Parameter | Value |
|---|---|
| **Comorbidities, frequency, *N* (%)** | |
| Hypertension | 96 (93.2) |
| Coronary heart disease | 43 (41.8) |
| Congestive heart failure | 23 (22.3) |
| History of ACVA | 29 (28.2) |
| Type 2 DM | 24 (23.3) |
| **Surgeries with various cardiac risks, frequency, *N* (%)** | |
| Low (on vertebral arteries) | 6 (5.8) |
| Moderate (on carotid arteries) | 77 (74.8) |
| High (on aorta) | 20 (19.4) |
| **Cardiovascular complications, frequency, *N* (%)** | |
| Perioperative | 12 (11.6) |
| **Cardiac risk assessment tools and blood indices** | |
| RCRI, points | 1–5 (2.0 [1.0–3.0]) |
| MICA CRI, % | 0.5–6.5 [0.73 [0.65–1.45]) |
| Khoronenko CRI, units | 0.02–0.62 (0.02 [0.02–0.05]) |
| AUB-HAS2 CRI, points | 1–3 (1.0 [1.0–2.0]) |
| Preoperative NLR, units | 0.51–4.6 (1.8 [1.5–2.6]) |
| Preoperative PLR, units | 49.2–254.1 (101.9 [74.9–136.6]) |
| **Cardiac biomarkers** | |
| $cTnI_1$, ng/mL | 0.01–0.025 (0.029 [0.02–0.05]) |
| $cTnI_2$, ng/mL | 0.01–3.7 (0.04 [0.02–0.12]) |
| $cTnI_3$, ng/mL | 0.01–0.79 (0.03 [0.02–0.06]) |
| $cTnI_{peak}$, ng/mL | 0.01–3.7 (0.05 [0.03–0.16]) |
| Postoperative troponin elevation, frequency, *N* (%) | 20 (19.4) |
| $NT\text{-}proBNP_1$, pg/mL | 23.9–774.3 (53.0 [42.0–185.3]) |
| $NT\text{-}proBNP_2$, pg/mL | 37.6–1035.0 (135.6 [59.2–258.1]) |
| $NT\text{-}proBNP_3$, pg/mL | 37.2–1013.3 (77.3 [48.2–269.4]) |
| $NT\text{-}proBNP_{peak}$, pg/mL | 37.6–1035.0 (189.1 [64.6–327.3] |

**Note.** For Tables 2, 4, 5: ACVA — acute cerebrovascular accident; DM — diabetes mellitus. The calculated cardiac risk scores, blood parameters and biomarkers are presented as min–max (*Me [LQ–HQ]*).

## Results and Discussion

**Survey results.** There were 54 positive responses from 34 respondents (33%), including 27 operated patients and 7 relatives of non-survivors. Of the 27 patients, 12 (44.5%) provided one positive response, 10 (37.0%) provided two, and 5 (18.5%) provided three. The remaining 69 respondents (67%) answered all questions negatively. The most commonly reported post-discharge CVCs included worsening CV symptoms and major adverse cardiovascular and cerebrovascular events (MACCE) (Table 3).

**Clinical and comorbidity parameters as predictors of post-discharge cardiovascular complications.** Sex, age, elevated cardiac risk index associated with surgery, and the presence of perioperative hospital complications and comorbidities were not associated with the composite outcome (Table 4). The only significant predictor was the American Society of Anesthesiologists (ASA) class. The dis-

**Table 3. CVCs within 12 months after vascular surgery identified from a questionnaire survey of 103 respondents.**

| Post-discharge CVCs | *N* (%) |
|---|---|
| Cardiac mortality | 7 (6.8) |
| Myocardial infarction | 2 (2.1) |
| ACVE | 6 (5.8) |
| Significant arrhythmias | 5 (4.8) |
| Progression of cardiovascular disease | 27 (26.2) |
| Hospitalization for cardiac indications | 7 (6.8) |
| MACCE | 16 (15.5) |
| Composite outcome | 34 (33.0) |

**Note.** ACVE — acute cerebrovascular event; MACCE — major adverse cardiovascular and cerebrovascular events.

criminative power of ASA was characterized by a model of moderate quality (AUC 0.600; 95% CI, 0.500–0.695; $P$ = 0.035). An ASA class > 3 did not provide adequate sensitivity, which was only 38.9% (95% CI, 23.1–56.5%) with a specificity of 81.2% (95% CI, 69.9–89.6%).

Comorbid congestive heart failure (CHF) was identified as a predictor of one-year cardiac mortality (Table 4). The discriminatory power of CHF as a predictor was characterized by a model of moderate quality (AUC 0.679; 95% CI, 0.581–0.767; $P$ = 0.047), with a sensitivity of 55.6% (95% CI, 21.2–86.3%) and a specificity of 80.2% (95% CI, 70.8–87.6%). Other common clinical indicators and comorbidities were not associated with mortality risk.

**Cardiac risk indices (CRI) and blood indices as predictors of post-discharge cardiovascular complications.** Several parameters were associated with the composite outcome: MICA CRI, AUB-HAS2 CRI, and platelet to lymphocyte ratio (PLR) (Table 5). The discriminatory power of MICA CRI (AUC 0.593; 95% CI 0.493–0.688; $P$ = 0.151) and AUB-HAS2 CRI (AUC 0.507; 95% CI 0.408–0.606; $P$ = 0.921) was not sufficient. The model based on PLR was of moderate quality (AUC 0.643; 95% CI, 0.535–0.740; $P$ = 0.028). The optimal threshold for PLR > 132.0 discriminated the composite outcome with a sensitivity of 50.0% (95% CI, 31.3–68.7%) and specificity of 85.25% (95% CI, 73.8–93.0%). Other parameters were not associated with the composite outcome.

The RCRI, Khoronenko CRI, and AUB-HAS2 CRI were found to be predictors of one-year cardiac mortality (Table 5). ROC analysis showed that RCRI did not provide a statistically significant model (AUC 0.679; 95% CI, 0.581–0.767; $P$ = 0.105). The discriminatory power of the Khoronenko CRI was characterized by a good quality model (AUC 0.726; 95% CI, 0.630-0.808; $P$ = 0.022), with a threshold of > 0.14 providing the best prediction of mortality, achieving a sensitivity of 55.6% (95% CI 21.2–86.3%) and a specificity of 90.6% (95% CI, 82.9–95.6%). The AUB-HAS2 CRI also provided a good quality model (AUC 0.689; 95% CI, 0.591–0.775; $P$ = 0.035). A threshold of > 1 for AUB-HAS2 CRI discriminated fatal outcomes with balanced sensitivity and specificity of 66.7% (95% CI, 29.9–92.5%) and 69.8% (95% CI, 59.6–78.7%), respectively. Neither MICA CRI nor blood indices were associated with the risk of one-year mortality.

**Cardiac biomarkers as predictors of post-discharge cardiovascular complications.** Perioperative

**Table 4. Association of clinical parameters and comorbidity with composite outcome and one-year cardiac mortality.**

| Parameter | OR | 95% CI | P-value |
|---|---|---|---|
| **Association with composite outcome** | | | |
| Sex | 0.9148 | 0.3784–2.2115 | 0.843 |
| Age | 1.0116 | 0.9527–1.0742 | 0.705 |
| Age over 65 years | 1.3039 | 0.5713–2.9761 | 0.528 |
| ASA class | 2.7413 | 1.1126–6.7541 | 0.028 |
| High cardiac risk surgery | 0.8768 | 0.3682–2.0880 | 0.766 |
| Perioperative hospital CVCs | 1.4286 | 0.4192–4.8678 | 0.568 |
| **Comorbidities** | | | |
| Hypertension | 1.3827 | 0.6035–3.1679 | 0.444 |
| Coronary heart disease | 1.4143 | 0.5406–3.6998 | 0.480 |
| Congestive heart failure | 1.2500 | 0.2298–6.8004 | 0.796 |
| ACVE | 1.0965 | 0.4425–2.7168 | 0.842 |
| DM | 2.0602 | 0.8062–5.2650 | 0.131 |
| **Association with one-year cardiac mortality** | | | |
| Sex | 0.5771 | 0.1214–2.7439 | 0.490 |
| Age | 1.0475 | 0.9366–1.1715 | 0.417 |
| Age over 65 years | 2.5000 | 0.4622–13.5210 | 0.287 |
| ASA class | 1.2000 | 0.2184–6.5931 | 0.834 |
| High cardiac risk surgery | 0.6458 | 0.1361–3.0648 | 0.582 |
| Perioperative hospital CVCs | 0.9659 | 0.1101–8.4733 | 0.975 |
| **Comorbidities** | | | |
| Coronary heart disease | 3.8158 | 0.7040–20.6817 | 0.120 |
| Congestive heart failure | 5.0658 | 1.2400–20.6956 | 0.024 |
| Hypertension | 0.4000 | 0.0412–3.8819 | 0.429 |
| ACVE | 1.0222 | 0.1869–5.5909 | 0.980 |
| DM | 2.6786 | 0.5555–12.9167 | 0.220 |

**Table 5. Association of CRIs and blood indices with composite outcome and one-year cardiac mortality**

| Parameter | OR | 95% CI | *P*-value |
|---|---|---|---|
| **Association with composite outcome** | | | |
| RCRI, points | 1.1047 | 0.7145–1.7080 | 0.654 |
| MICA CRI, % | 1.6051 | 1.0899–2.3638 | 0.017 |
| Khoronenko CRI, units | 2.6700 | 0.0893–79.7995 | 0.571 |
| AUB-HAS2 CRI, points | 2.1106 | 1.0260–4.3414 | 0.042 |
| Preoperative NLR, units | 0.8959 | 0.4643–1.7288 | 0.743 |
| Preoperative PLR, units | 1.0120 | 1.0018–1.0222 | 0.021 |
| **Association with one-year cardiac mortality** | | | |
| RCRI, points | 2.1024 | 1.0572–4.1813 | 0.034 |
| MICA CRI, % | 1.1590 | 0.6645–2.0215 | 0.603 |
| Khoronenko CRI, units | 103.76 | 1.8752–5796.55 | 0.024 |
| AUB-HAS2 CRI, points | 3.1902 | 1.1040–9.2181 | 0.032 |
| Preoperative NLR, units | 1.5539 | 0.6057–3.9866 | 0.359 |
| Preoperative PLR, units | 1.0058 | 0.9891–1.0228 | 0.499 |

**Table 6. Association of cardiac biomarkers with composite outcome and one-year cardiac mortality.**

| Parameter | OR | 95% CI | *P*-value |
|---|---|---|---|
| **Association with composite outcome** | | | |
| $cTnI_1$ | 778.3 | 0.1251–8415.6 | 0.135 |
| $cTnI_2$ | 2.1576 | 0.5111–9.1087 | 0.295 |
| $cTnI_3$ | 0.538 | 0.0012–10.2985 | 0.342 |
| $cTnI_{peak}$ | 1.6283 | 0.5450–4.8647 | 0.383 |
| $NT\text{-}proBNP_1$ | 1.0047 | 1.0015–1.0079 | 0.004 |
| $NT\text{-}proBNP_2$ | 1.0033 | 1.0010–1.0055 | 0.004 |
| $NT\text{-}proBNP_3$ | 1.0071 | 1.0038–1.0104 | <0.0001 |
| $NT\text{-}proBNP_{peak}$ | 1.0046 | 1.0023–1.0069 | 0.0001 |
| **Association with one-year cardiac mortality** | | | |
| $cTnI_1$ | 1.3667 | 0.1427–13.0900 | 0.786 |
| $cTnI_2$ | 0.8197 | 0.0639–10.5074 | 0.879 |
| $cTnI_3$ | 0.0310 | 0.0000–9669.3941 | 0.590 |
| $cTnI_{peak}$ | 0.4178 | 0.0049–35.3554 | 0.699 |
| $NT\text{-}proBNP_1$ | 1.0039 | 1.0003–1.0076 | 0.035 |
| $NT\text{-}proBNP_2$ | 1.0040 | 1.0014–1.0066 | 0.002 |
| $NT\text{-}proBNP_3$ | 1.0034 | 1.0008–1.0060 | 0.011 |
| $NT\text{-}proBNP_{peak}$ | 1.0039 | 1.0015–1.0063 | 0.001 |

cardiac troponin I (cTnI) levels were not associated with the composite outcome or one-year mortality (Table 6). Cardiac troponin elevation in the post-operative period also did not predict the composite outcome (OR 1.3571; 95% CI, 0.4980–3.6982; $P = 0.551$) or one-year cardiac mortality (OR 1.2381; 95% CI, 0.2371–6.4660; $P = 0.801$).

NT-proBNP levels at all perioperative stages as well as $NT\text{-}proBNP_{peak}$ levels were associated with the composite outcome (Table 6). The discriminatory power of NT-proBNP1 for the composite outcome was characterized by a model of moderate quality, whereas the remaining NT-proBNP measurements showed models of good quality (Table 7, Fig. *a*). Sensitivity and specificity for $NT\text{-}proBNP_3$ and $NT\text{-}proBNP_{peak}$ exceeded 70% and were well balanced. The cut-off value for $NT\text{-}proBNP_3$ was found to be close to the upper limit of normal, while the $NT\text{-}proBNP_{peak}$ levels were above it.

All levels of NT-proBNP were associated with one-year cardiac mortality (Table 6). In the ROC analysis (Table 7), the prognostic model quality (Fig. *b*) was good for $NT\text{-}proBNP_1$ and $NT\text{-}proBNP_2$ and very good for $NT\text{-}proBNP_3$ and $NT\text{-}proBNP_{peak}$. Thresholds for $NT\text{-}proBNP_3$ and $NT\text{-}proBNP_{peak}$ effectively discriminated patients at risk for 1-year mortality, with sensitivity and specificity greater than 70%.

The observed incidence of specific CVCs in the year following vascular surgery was very close to previously published data on the occurrence of various post-discharge CVCs in non-cardiac surgery patients [3, 4, 14]. For example, myocardial infarction was reported to occur in up to 1.6% of cases, major adverse cardiovascular and cerebrovascular events (MACCE) ranged from 8.8% to 20.6%, and cardiac mortality within 12 months was reported to range from 3.7% to 4.2% [3,4].

It is important to note that comparing data from different authors on the prevalence of long-term post-discharge CVCs is challenging. Published studies differ in design, patient categories, follow-up periods, and other characteristics, including terminology. In this study, we considered the presence of all cardiovascular complications and events as a composite outcome. A similar approach was proposed by S. S. Murashko et al. [22], who emphasized the clinical significance and economic feasibility

**Table 7. Discriminatory power of perioperative NT-proBNP values in relation to composite outcome and one-year cardiac mortality.**

| Parameters | AUC | 95% CI | *P*-value | Cut-off value, pg/mL | Sensitivity, % (95% CI) | Specificity, % (95% CI) |
|---|---|---|---|---|---|---|
| **Discriminatory power for composite outcome** | | | | | | |
| NT-roBNP$_1$ | 0.691 | 0.592–0.779 | 0.0006 | > 54.6 | 64.7 (46.5–80.3) | 60.3 (47.7–72.0) |
| NT-roBNP$_2$ | 0.712 | 0.614–0.797 | 0.0001 | > 151.1 | 68.6 (50.7–83.1) | 62.7 (50.0–74.2) |
| NT-roBNP$_3$ | 0.795 | 0.702–0.869 | < 0.0001 | > 179.3 | 70.6 (52.5–84.9) | 81.8 (70.4–90.2) |
| NT-proBNP$_{peak}$ | 0.779 | 0.688–0.854 | < 0.0001 | > 248.5 | 72.2 (54.8–85.8) | 75.4 (63.5–84.9) |
| **Discriminatory power for one-year cardiac mortality** | | | | | | |
| NT-proBNP$_1$ | 0.761 | 0.666–0.840 | 0.0004 | > 142.1 | 66.7 (29.9–92.5) | 73.1 (62.9–81.8) |
| NT-proBNP$_2$ | 0.786 | 0.693–0.861 | 0.0004 | > 289.3 | 66.7 (29.9–92.5) | 83.8 (74.8–90.7) |
| NT-proBNP$_3$ | 0.833 | 0.745–0.900 | < 0.0001 | > 269.4 | 77.8 (40.0–97.2) | 79.1 (69.3–86.9) |
| NT-proBNP$_{peak}$ | 0.836 | 0.751–0.901 | < 0.0001 | > 302.7 | 88.9 (51.8–99.7) | 75.0 (65.1–83.3) |

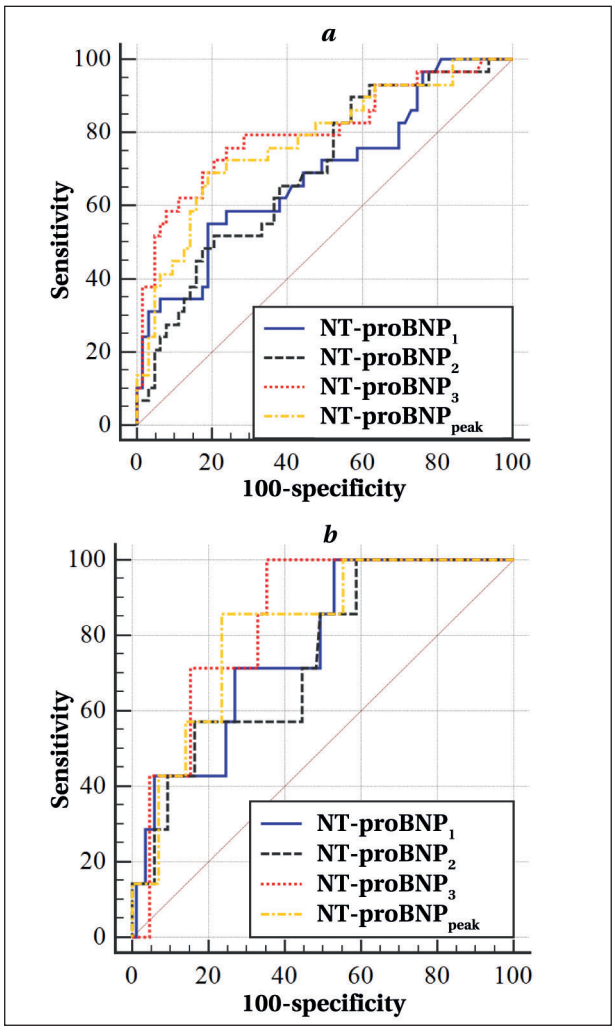


**Fig. ROC curves showing the sensitivity and specificity of perioperative NT-proBNP levels in relation to the composite outcome (*a*) and the risk of one-year cardiac mortality (*b*).**

of considering any abnormality in the cardiovascular system during the postoperative period (any cardiovascular events, ACVE). According to these researchers, the incidence of ACVE after non-cardiac surgery can be as high as 54.7%. While such an approach has not been applied to vascular surgery within 12 months of surgery, previous attempts have been made to expand the concept of long-term CVCs by identifying four etiological and pathogenetic variants of postoperative myocardial injury [3]. Despite the particularities of the studies conducted, clinicians are unanimous in emphasizing the wide prevalence of post-discharge CVCs in non-cardiac surgery and their highly adverse prognostic significance [1, 3, 4, 6, 14].

In our study, ASA class > 3 was identified as a predictor of CVCs within the first year after vascular surgery. The multicenter STOPRISK study also found that preoperative physical status was a significant risk factor for postoperative complications [25]. In a previous study in a mixed population of noncardiac surgery patients, we found an association between ASA class and post-discharge CVCs [27]. However, due to its very low sensitivity, ASA class > 3 cannot be recommended as an accurate predictor of various cardiac events after vascular surgery [35].

Patients with chronic heart failure (CHF) had a higher risk of cardiac death within one year after vascular surgery. Some investigators have previously suggested that CHF may double the risk of one-year cardiac mortality in patients undergoing vascular surgery [14]. A similar pattern was found in the mixed surgical population [27]. However, the sensitivity of the predictor indicated a high risk of false-positive predictions. Other predictors of post-discharge cardiovascular complications and cardiac mortality were not identified in the study patients. We did not see the correlation between delayed mortality and early perioperative complications reported by other authors [36, 37].

Although developed and validated primarily to predict in-hospital cardiovascular events [31–34], cardiac risk indices have been evaluated as predictors of 1-year cardiac mortality [15]. We have shown that, although MICA CRI and AUB-HAS2 CRI were associated with an increased risk of cardiovascular complications, they did not show sufficient discriminatory power for composite outcomes. However, AUB-HAS2 CRI proved to be a significant predictor of 1-year cardiac mortality, consistent with previous findings highlighting its advantages over the Revised Cardiac Risk Index (RCRI) [38]. Notably,

the RCRI failed to achieve significant discriminatory power for post-discharge mortality in our study. The predictive ability of the AUB-HAS2, although statistically significant, was unreliable as its 95% confidence intervals for sensitivity indicated inadequate effectiveness [35]. Similarly, the Khoronenko CRI showed inadequate sensitivity despite good model quality, indicating a high likelihood of false-positive predictions.

The risk of composite outcomes was also associated with the preoperative platelet to lymphocyte ratio (PLR). The relationship between PLR and the likelihood of early postoperative cardiovascular complications in non-cardiac surgery has been investigated in several focused studies [39, 40]. In addition, PLR has been associated with outcomes in certain cardiovascular diseases [41]. This association highlights the potential role of this blood index as marker for postoperative cardiovascular complications. However, the low sensitivity of PLR as a predictor limits its utility for widespread clinical application.

In the studied patient cohort, neither cardiac troponin I (cTnI) levels nor the presence of elevated serum troponin were identified as predictors of composite outcomes or one-year cardiovascular mortality. This finding contrasts with the prevailing consensus on the importance of cardiac troponins (cTn) in assessing the risk of post-discharge cardiovascular complications [4, 16, 42]. Previous studies have demonstrated the prognostic significance of both preoperative [43, 44] and postoperative [44, 45] cTn levels. However, the lack of predictive significance in this study may be due to several factors:

1. Differential predictive value of cTn isoforms: In certain clinical scenarios, cTnI may be less accurate than cTnT in predicting postoperative complications [46].

2. Analytical variability: The characteristics of the reagents and the specific equipment used in immunoassays can influence cTn measurements. Methodological variability and lack of standardization in cTn assays remain significant challenges, as highlighted by leading experts [47, 48].

Thus, despite these findings, it would be premature to exclude cTnI or cTnT as candidate predictors of postoperative major adverse cardiac events (MACE) or cardiovascular complications in general. Further studies are needed to refine the role of cTn monitoring in risk stratification and to validate national laboratory techniques for cTn analysis.

Preoperative levels of NT-proBNP and/or active B-type natriuretic peptide (BNP) are widely recognized as highly informative predictors of perioperative cardiovascular complications [11–13, 42]. Meanwhile, the utility of assessing postoperative NT-proBNP/BNP levels remains controversial. Some researchers argue that there is insufficient evidence to confirm their prognostic value [42]. However, several studies and meta-analyses suggest otherwise. They have shown that postoperative NT-proBNP/BNP levels outperform other predictors in predicting cardiovascular complications 6 and 12 months after surgery as well as one-year mortality [15, 17, 49].

Of all the predictors examined, only postoperative NT-proBNP levels reliably predicted the risk of CVCs and one-year cardiac mortality. NT-proBNP levels at discharge and peak levels during the postoperative period were found to be effective predictors of composite outcomes [35]. One-year cardiac mortality was reliably predicted only by the NT-proBNP$_{peak}$ values. Specifically, NT-proBNP cut-off levels associated with composite outcomes were near the upper end of the reference range, which is consistent with previous research on the predictive value of the biomarker for in-hospital CVCs [50]. NT-proBNP$_{peak}$ levels 1.5 times above normal were reliable predictors of one-year mortality. This evidence supports the use of serial NT-proBNP measurements in the postoperative period to identify levels associated with poor surgical outcomes. This approach has been used successfully in cardiac surgery patients [51] and our findings support its use in non-cardiac surgery.

It can be concluded that more than 30% of patients undergoing vascular surgery experience various CVCs within the first year after surgery. Although general clinical parameters, cardiac risk indices, and platelet to lymphocyte ratio (PLR) have been associated with the risk of post-discharge CVCs and cardiac mortality, their efficacy as predictors in clinical practice remains limited. Prediction of one-year CVCs and mortality was reliably achieved by assessment of NT-proBNP levels in the postoperative period. However, the predictive value of troponins requires further investigation to clarify its clinical applicability.

**Study limitation.** The study protocol was not registered in advance.

## Conclusion

Within 12 months after vascular surgery, 33% of patients develop cardiovascular complications, including cardiac death in 6.8% of cases. These complications are reliably predicted by discharge NT-proBNP levels greater than 179 pg/mL and postoperative NT-proBNP$_{peak}$ levels greater than 248 pg/mL. Postoperative NT-proBNP levels greater than 303 pg/mL predict cardiac mortality within one year. Other variables associated with the risk of post-discharge CVCs do not show sufficient predictive power to be considered useful in clinical practice.

## References


1. *Álvarez-Garcia J., Popova E., Vives-Borrás M., de Nadal M., Ordonez-Llanos J., Rivas-Lasarte M., Moustafa A. H., et al.* Myocardial injury after major noncardiac surgery evaluated with advanced cardiac imaging: a pilot study. *BMC Cardiovasc Disord.* 2023; 23 (1): 78. DOI: 10.1186/s12872-023-03065-6. PMID: 36765313.
2. *Kashlan B., Kinno M., Syed M.* Perioperative myocardial injury and infarction after noncardiac surgery: a review of pathophysiology, diagnosis, and management. *Front Cardiovasc Med.* 2024; 11: 1323425. DOI: 10.3389/fcvm.2024.1323425. PMID: 38343871.
3. *Puelacher C., Gualandro D. M., Glarner N., Lurati Buse G., Lampart A., Bolliger D., Steiner L. A., et al,* BASEL-PMI Investigators. Long-term outcomes of perioperative myocardial infarction/injury after noncardiac surgery. *Eur Heart J.* 2023; 44 (19): 1690–1701. DOI: 10.1093/eurheartj/ehac798. PMID: 36705050.
4. *Sazgary L., Puelacher C., Lurati Buse G., Glarner N., Lampart A., Bolliger D., Steiner L., et al.,* BASEL-PMI Investigators. Incidence of major adverse cardiac events following non-cardiac surgery. *Eur Heart J Acute Cardiovasc Care.* 2021; 10 (5): 550–558. DOI: 10.1093/ehjacc/zuaa008. PMID: 33620378.
5. *Jerath A., Austin P. C., Ko D. T., Wijeysundera H. C., Fremes S., McCormack D., Wijeysundera D. N.* Socioeconomic status and days alive and out of hospital after major elective noncardiac surgery: a population-based cohort study. *Anesthesiology.* 2020; 132 (4): 713–722. DOI: 10.1097/ALN.0000000000003123. PMID: 31972656.
6. *Smilowitz N. R., Beckman J. A., Sherman S. E., Berger J. S.* Hospital readmission following perioperative acute myocardial infarction associated with non-cardiac surgery. *Circulation.* 2018; 137 (22): 2332–2339. DOI: 10.1161/CIRCULATIONAHA.117.032086. PMID: 29525764.
7. *Park J., Lee J. H.* Myocardial injury in noncardiac surgery. *Korean J Anesthesiol.* 2022; 75 (1): 4–11. DOI: 10.4097/kja.21372. PMID: 34657407.
8. *Заболотских И. Б., Потиевская В. И., Баутин А. Е., Григорьев Е. В., Григорьев С. В., Грицан А. И., Киров М. Ю., с соавт.* Периоперационное ведение пациентов с ишемической болезнью сердца. *Анестезиология и реаниматология.* 2020; (3): 5–16. *Zabolotskikh I. B., Potievskaya V. I., Bautin A. E., Grigor'ev E. V., Grigoryev S. V., Gritsan A. I., Kirov M. Yu., et al.* Perioperative management of patients with coronary artery disease. *Russian Journal of Anesthesiology and Reanimatology = Anesteziologiya i Reanimatologiya.* 2020; (3): 5–16. (In Russ.) DOI: 10.17116/anaesthesiology20200315.
9. *Заболотских И. Б., Баутин А. Е., Замятин М. Н., Лебединский К. М., Потиевская В. И., Трембач Н. В.* Периоперационное ведение пациентов с хронической сердечной недостаточностью. *Анестезиология и реаниматология.* 2021; (3): 6–27. *Zabolotskikh I. B., Bautin A. E., Zamyatin M. N., Lebedinskii K. M., Potievskaya V. I., Trembach N. V.* Perioperative management of patients with heart failure. *Russian Journal of Anesthesiology and Reanimatology = Anesteziologiya i Reanimatologiya.* 2021; (3): 6–27. (In Russ.). DOI: 10.17116/anaesthesiology 20210316.
10. *Сумин А. Н., Дупляков Д. В., Белялов Ф. И., Баутин А. Е., Безденежных А. В., Гарькина С. В., Гордеев М. Л., с соавт.* Рекомендации по оценке и коррекции сердечно-сосудистых рисков при несердечных операциях 202323. *Российский кардиологический журнал.* 2023; 28 (8): 5555. *Sumin A. N., Duplyakov D. V., Belyalov F. I., Bautin A. E., Bezdenezhnykh A. V., Garkina S. V., Gordeev M. L., et al.* Assessment and modification of cardiovascular risk in non-cardiac surgery. Clinical guidelines 2023. *Russian Journal of Cardiology = Rossiysky Kardiologichesky Zhurnal.* 2023; 28 (8): 5555. (In Russ.). DOI: 10.15829/1560-4071-20235555.
11. *Alphonsus C. S., Naidoo N., Motshabi Chakane P., Cassimjee I., Firfiray L., Louwrens H., Van der Westhuizen J., et al.* South African cardiovascular risk stratification guideline for non-cardiac surgery. *S Afr Med J.* 2021; 111 (10b): 13424. DOI: 10.7196/SAMJ.2021.v111i10b.15874. PMID: 34949237.
12. *Halvorsen S., Mehilli J., Cassese S., Hall T. S., Abdelhamid M., Barbato E., De Hert S., et al.* ESC Scientific Document Group. 2022 ESC Guidelines on cardiovascular assessment and management of patients undergoing non-cardiac surgery. *Eur Heart J.* 2022; 43 (39): 3826–3924. DOI: 10.1093/eurheartj/ehac270. PMID: 36017553.
13. *Smilowitz N. R., Berger J. S.* Perioperative cardiovascular risk assessment and management for noncardiac surgery. A review. *JAMA.* 2020; 324 (3): 279–290. DOI: 10.1001/jama.2020.7840. PMID: 32692391.
14. *Beaulieu R. J., Sutzko D. C., Albright J., Jeruzal E., Osborne N. H., Henke P. K.* Association of high mortality with postoperative myocardial infarction after major vascular surgery despite use of evidence-based therapies. *JAMA Surg.* 2020; 155 (2): 131–137. DOI: 10.1001/jamasurg.2019.4908. PMID: 3180000.
15. *Katsanos S., Babalis D., Kafkas N., Mavrogenis A., Leong D., Parissis J., Varounis C., et al.* B-type natriuretic peptide vs. cardiac risk scores for prediction of outcome following major orthopedic surgery. *J Cardiovasc Med (Hagerstown).* 2015; 16 (6): 465–471. DOI: 10.2459/JCM.0000000000000210. PMID: 25469732.
16. *Puelacher C., Lurati Buse G., Seeberger D., Sazgary L., Marbot S., Lampart A., Espinola J., et al.* BASEL-PMI Investigators. Perioperative myocardial injury after noncardiac surgery: incidence, mortality, and characterization. *Circulation.* 2018; 137 (12): 1221–1232. DOI: 10.1161/CIRCULATIONAHA.117.030114. PMID: 29203498.
17. *Rodseth R. N., Biccard B. M., Le Manach Y., Sessler D. I., Lurati Buse G. A., Thabane L., Schutt R. C., et al.* The prognostic value of pre-operative and post-operative B-type natriuretic peptides in patients undergoing noncardiac surgery: B-type natriuretic peptide and N-terminal fragment of pro-B-type natriuretic peptide: a systematic review and individual patient data meta-analysis. *J Am Coll Cardiol.* 2014; 63 (2): 170–180. DOI: 10.1016/j.jacc.2013.08.1630. PMID: 24076282.
18. *Александрова Е. А., Хороненко В. Э., Маланова А. С., Захаренкова Ю. С., Суворин П. А.* Оценка кардиопротективных свойств лидокаина как адъювантного компонента общей анестезии при онкоторакальных вмешательствах. *Анестезио-*

*логия и реаниматология.* 2023; (1): 39–48. *Aleksandrova E. A., Khoronenko V. E., Malanova A. S., Zakharenkova Yu. S., Suvorin P. A.* Cardiac protective properties of lidocaine as adjuvant component of general anesthesia in thoracic surgery for cancer. *Russian Journal of Anesthesiology and Reanimatology = Anesteziologiya i Reanimatologiya.* 2023; (1): 39–48. (In Russ.). DOI: 10.17116/anaesthesiology202301139.

19. *Корниенко А. Н., Добрушина О. Р., Зинина Е. П.* Профилактика кардиальных осложнений внесердечных операций. *Общая реаниматология.* 2011; 7 (5): 57–66. *Korniyenko A. N., Dobrushina O. R., Zinina E. P.* Differentiated prevention of cardiac complications of extracardiac surgery. *General Reanimatology = Obshchaya Reanimatologiya.* 2011; 7 (5): 57–66. (In Russ.&Eng.). DOI: 10.15360/1813-9779-2011-5-57.
20. *Лихванцев В. В., Убасев Ю. В., Скрипкин Ю. В., Забелина Т. С., Сунгуров В. А., Ломиворотов В. В., Марченко Д. Н.* Предоперационная профилактика сердечной недостаточности в некардиальной хирургии. *Общая реаниматология.* 2016; 12 (3): 48–61. *Likhvantsev V. V., Ubasev Yu. V., Skripkin Yu. V., Zabelina T. S., Sungurov V. A., Lomivorotov V. V., Marchenko D. N.* Preoperative prevention of heart failure in noncardiac surgery. *General Reanimatology = Obshchaya Reanimatologiya.* 2016; 12 (3): 48–61. (In Russ.&Eng.). DOI: 10.15360/1813-9779-2016-3-48-61.
21. *Мороз В. В., Марченко Д. Н., Скрипкин Ю. В., Забелина Т. С., Овезов А. М., Лихванцев В. В.* Периоперационные предикторы неблагоприятного исхода сосудистых вмешательств. *Общая реаниматология.* 2017; 13 (3): 6–12. *Moroz V. V., Marchenko D. N., Skripkin Yu. V., Zabelina T. S., Ovezov A. M., Likhvantsev V. V.* Perioperative predictors of unfavorable outcome of vascular surgery. *General Reanimatology = Obshchaya Reanimatologiya.* 2017; 13 (3): 6–12. (In Russ.&Eng.). DOI: 10.15360/1813-9779-2017-3-6-12.
22. *Мурашко С. С., Бернс С. А., Пасечник И. Н.* Сердечно-сосудистые осложнения в некардиальной хирургии: что остается вне поля зрения? *Кардиоваскулярная терапия и профилактика.* 2024; 23 (1): 3748. *Murashko S. S., Berns S. A., Pasechnik I. N.* Cardiovascular complications in non-cardiac surgery: what remains out of sight? *Cardiovascular Therapy and Prevention = Kardiovaskulyarnaya Terapiya i Profilaktika.* 2024; 23 (1): 3748. (In Russ.). DOI: 10.15829/1728-8800-2024-3748.
23. *Сумин А. Н.* Оценка и коррекция риска кардиальных осложнений при некардиальных операциях – что нового? *Рациональная Фармакотерапия в Кардиологии.* 2022; 18 (5): 591–599. *Sumin A. N.* Assessment and correction of the cardiac complications risk in non-cardiac operations — what's new? *Rational Pharmacotherapy in Cardiology = Ratsionalnaya Farmakoterapiya v Kardiologii.* 2022; 18 (5): 591–599. (In Russ.). DOI: 10.20996/1819-6446-2022-10-04.
24. *Чомахидзе П. Ш., Полтавская М. Г., Мозжухина Н. В., Фроловичева И. С., Якубовская Е. Е., Гришина А. А.* Сердечно-сосудистые осложнения при некардиологических хирургических вмешательствах. *Кардиология и сердечно-сосудистая хирургия.* 2012; 5 (1): 36–41. *Chomakhidze P. Sh., Poltavskaya M. G., Mozzhukhina N. V., Frolovicheva I. S., Iakubovskaia E. E., Grishina A. A.* Cardiovascular complications at non-cardiac surgical interventions. *Russian Journal of Cardiology and Cardiovascular* Surgery = *Kardiologiya i Serdechno-Sosudistaya Khirurgiya.* 2012; 5 (1): 36–41. (In Russ.).
25. *Заболотских И. Б., Трембач Н. В., Магомедов М. А., Краснов В. Г., Черниенко Л. Ю., Шевырев С. Н., Попов А. С., с соавт.* Возможности предоперационной оценки риска неблагоприятного исхода абдоминальных операций: предварительные результаты многоцентрового исследования STOPRISK. *Вестник интенсивной терапии им. А. И. Салтанова.* 2020; 4: 12–27. *Zabolotskikh I. B., Trembach N. V., Magomedov N. V., Krasnov V. G., Chernienko L. Yu., Shevyrev S. N., Popov A. S., et al.* Possibilities of preoperative assessment of the risk of adverse outcomes after abdominal surgery: preliminary results of the multicenter STOPRISK study. *Annals of Critical Care = Vestnik Intensivnoy Terapii im AI Saltanova.* 2020; 4: 12–27. (In Russ.). DOI: 10.21320/1818-474X-2020-4-12-27.
26. *Трембач Н. В., Магомедов М. А., Краснов В. Г., Черниенко Л. Ю., Шевырев С. Н., Попов А. С., Тютюнова Е. В., с соавт.* Влияние отмены ИАПФ/БРА на риск развития послеоперационных осложнений в абдоминальной хирургии. *Общая реаниматология.* 2023; 19 (5): 21–30. *Trembach N. V., Magomedov M. A., Krasnov V. G., Chernienko L. Yu., Shevyrev S. N., Popov A. S., Tyutyunova E. V., et al.* The effect of ACE inhibitors/ARBs withdrawal on the risk of postoperative complications in abdominal surgery. *General Reanimatology = Obshchaya Reanimatologiya.* 2023; 19 (5): 21–30. (In Russ.&Eng.). DOI: 10.15360/1813-9779-2023-5-2328.
27. *Соколов Д. А., Любошевский П. А., Староверов И. Н., Козлов И. А.* Постгоспитальные сердечно-сосудистые осложнения у больных, перенесших некардиохирургические операции. *Вестник анестезиологии и реаниматологии.* 2021; 18 (4): 62–72. *Sokolov D. A., Lyuboshevsky P. A., Staroverov I. N., Kozlov I. A.* Posthospital cardiovascular complications in patients after non-cardiac surgery. *Messenger of Anesthesiology and Resuscitation = Vestnik Anesthesiologii i Reanimatologii.* 2021; 18 (4): 62–72. (In Russ.). DOI: 10.21292/2078-5658-2021-18-4-62-72.
28. *Green S. B.* How many subjects does it take to do a regression analysis. *Multivariate Behav Res.* 1991; 26 (3): 499–510. DOI: 10.1207/s15327906mbr2603_7. PMID: 26776715.
29. *Hermans W. R., Foley D. P., Rensing B. J., Rutsch W., Heyndrickx G. R., Danchin N., Mast G., et al.* Usefulness of quantitative and qualitative angiographic lesion morphology, and clinical characteristics in predicting major adverse cardiac events during and after native coronary balloon angioplasty. CARPORT and MERCATOR Study Groups. *Am J Cardiol.* 1993; 72 (1): 14–20. DOI: 10.1016/0002-9149 (93)90211-t. PMID: 8517422.
30. *Smilowitz N. R., Gupta N., Ramakrishna H., Guo Y., Berger J. S., Bangalore S.* Perioperative major adverse cardiovascular and cerebrovascular events associated with noncardiac surgery. *JAMA Cardiol.* 2017; 2 (2): 181–187. DOI: 10.1001/jamacardio.2016.4792. PMID: 28030663.
31. *Lee T. H., Marcantonio E. R., Mangione C. M., Thomas E. J., Polanczyk C. A., Cook E. F., Sugarbaker D. J.,*

*et al.* Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. *Circulation.* 1999; 100 (10): 1043–1049. DOI: 10.1161/01.cir.100.10.1043. PMID: 10477528.
32. *Gupta P. K., Gupta H., Sundaram A., Kaushik M., Fang X., Miller W. J., Esterbrooks D. J., et al.* Development and validation of a risk calculator for prediction of cardiac risk after surgery. *Circulation.* 2011; 124 (4): 381–387. DOI: 10.1161/CIRCULATIONAHA.110.015701. PMID: 21730309.
33. *Хороненко В. Э., Осипова Н. А., Лагутин М. Б., Шеметова М. М.* Диагностика и прогнозирование степени риска периоперационных сердечно-сосудистых осложнений у гериатрических пациентов в онкохирургии. *Анестезиология и реаниматология.* 2009; (4): 22–27. *Khoronenko V. E., Osipova N. A., Lagutin M. B., Shemetova M. M.* Diagnosis and risk assessment of perioperative cardiovascular complications in geriatric patients in oncological surgery. *Anesteziol Reanimatol = Anesteziologiya i Reanimatologiya.* 2009; (4): 22–27. (In Russ.) PMID: 19827200.
34. *Dakik H. A., Sbaity E., Msheik A., Kaspar C., Eldirani M., Chehab O., Abou Hassan O., et al.* AUB-HAS2 Cardiovascular risk index: performance in surgical subpopulations and comparison to the revised cardiac risk index. *J Am Heart Assoc.* 2020; 9 (10): e016228. DOI: 10.1161/JAHA.119.016228. PMID: 32390481.
35. *Реброва О. Ю.* Эффективность систем поддержки принятия врачебных решений: способы и результаты оценки. *Клиническая и экспериментальная тиреоидология.* 2019; 15 (4): 148–155. *Rebrova O. Y.* Efficacy of clinical decision support systems: methods and estimates. *Clinical and experimental thyroidology = Klinicheskaya i Eksperimentalnaya Tireoidologiya.* 2019; 15 (4): 148–155. DOI: 10.14341/ket12377.
36. *Choi B., Oh A. R., Park J., Lee J. H., Yang K., Lee D. Y., Rhee S. Y., et al.* Perioperative adverse cardiac events and mortality after non-cardiac surgery: a multicenter study. *Korean J Anesthesiol.* 2024; 77 (1): 66–76. DOI: 10.4097/kja.23043. PMID: 37169362.
37. *Oh A. R., Park J., Lee J. H., Kim H., Yang K., Choi J. H., Ahn J., et al.* Association between perioperative adverse cardiac events and mortality during one-year follow-up after noncardiac surgery. *J Am Heart Assoc.* 2022; 11 (8): e024325. DOI: 10.1161/JAHA.121.024325. PMID: 35411778.
38. *Tamim H., Mailhac A., Dakik H. A.* Comparison of the American University of Beirut (AUB)-HAS2 and revised cardiac risk indexes in elective noncardiac surgery. *Am J Cardiol.* 2023; 188: 22–23. DOI: 10.1016/j.amjcard.2022.11.016. PMID: 36462270.
39. *Соколов Д. А., Каграманян М. А., Козлов И. А.* Расчетные гематологические индексы как предикторы сердечно-сосудистых осложнений в некардиальной хирургии (пилотное исследование). *Вестник анестезиологии и реаниматологии.* 2022; 19 (2): 14–22. *Sokolov D. A., Kagramanyan M. A., Kozlov I. A.* Calculated hematological indices as predictors of cardiovascular complications in noncardiac surgery (Pilot Study). *Messenger of anesthesiology and resuscitation = Vestnik Anesthesiologii i Reanimatologii.* 2022; 19 (2): 14–22. (In Russ.). DOI: 10.21292/2078-5658-2022-19-2-14-22.
40. *Larmann J., Handke J., Scholz A. S., Dehne S., Arens C., Gillmann H. J., Uhle F., et al.* Preoperative neutrophil to lymphocyte ratio and platelet to lymphocyte ratio are associated with major adverse cardiovascular and cerebrovascular events in coronary heart disease patients undergoing non-cardiac surgery. *BMC Cardiovasc Disord.* 2020; 20 (1): 230. DOI: 10.1186/s12872-020-01500-6. PMID: 32423376.
41. *Чаулин А. М., Григорьева Ю. В., Павлова Т. В., Дупляков Д. В.* Диагностическая ценность клинического анализа крови при сердечно-сосудистых заболеваниях. *Российский кардиологический журнал.* 2020; 25 (12): 3923. *Chaulin A. M., Grigorieva Yu. V., Pavlova T. V., Duplyakov D. V.* Diagnostic significance of complete blood count in cardiovascular patients. *Russian Journal of Cardiology = Rossiysky Kardiologichesky Zhurnal.* 2020; 25 (12): 3923. (in Russ.). DOI: 10.15829/1560-4071-2020-3923.
42. *Buse G. L., Pinto B. B., Abelha F., Abbott T. E. F., Ackland G., Afshari A., De Hert S., et al.* ESAIC focused guideline for the use of cardiac biomarkers in perioperative risk evaluation. *Eur J Anaesthesiol.* 2023; 40 (12): 888–927. DOI: 10.1097/EJA.0000000000001865. PMID: 37265332.
43. *Bolliger D., Seeberger M. D., Lurati Buse G. A., Christen P., Rupinski B., Gürke L., Filipovic M.* A preliminary report on the prognostic significance of preoperative brain natriuretic peptide and postoperative cardiac troponin in patients undergoing major vascular surgery. *Anesth Analg.* 2009; 108 (4): 1069–1075. DOI: 10.1213/ane.0b013e318194f3e6. PMID: 19299763.
44. *Millán-Figueroa A., López-Navarro J. M., Pérez-Díaz I., Galindo-Uribe J., García-Martínez B., Del Villar-Velasco S. L., López-Gómez T., et al.* Evaluation of perioperative high-sensitive cardiac troponin I as a predictive biomarker of major adverse cardiovascular events after noncardiac surgery. *Rev Invest Clin.* 2020; 72 (2): 110–118. DOI: 10.24875/RIC.19002888. PMID: 32284625.
45. *Kim B. S., Kim T. H., Oh J. H., Kwon C. H., Kim S. H., Kim H. J., Hwang H. K., et al.* Association between preoperative high sensitive troponin I levels and cardiovascular events after hip fracture surgery in the elderly. *J Geriatr Cardiol.* 2018; 15 (3): 215–221. DOI: 10.11909/j.issn.1671-5411.2018.03.002. PMID: 29721000.
46. *Gualandro D. M., Puelacher C., Lurati Buse G., Lampart A., Strunz C., Cardozo F. A., Yu P. C., et al.* TropoVasc and BASEL-PMI Investigators. Comparison of high-sensitivity cardiac troponin I and T for the prediction of cardiac complications after noncardiac surgery. *Am Heart J.* 2018; 203: 67–73. DOI: 10.1016/j.ahj.2018.06.012. PMID: 30041065.
47. *Collinson P. O., Apple F., Jaffe A. S.* Use of troponins in clinical practice: evidence in favour of use of troponins in clinical practice: evidence in favour of use of troponins in clinical practice. *Heart.* 2020; 106 (4): 253–255. DOI: 10.1136/heartjnl-2019-315622. PMID: 31672780.
48. *Thygesen K., Mair J., Giannitsis E., Mueller C., Lindahl B., Blankenberg S., Huber K., et al, Study Group on Biomarkers in Cardiology of ESC Working Group on Acute Cardiac Care.* How to use high-sensitivity cardiac troponins in acute cardiac care. *Eur Heart J.*

2012; 33 (18): 2252–2257. DOI: 10.1093/eurheartj/ehs154. PMID: 22723599.
49. *Chong C. P., Lim W. K., Velkoska E., van Gaal W. J., Ryan J. E., Savige J., Burrell L. M.* N-terminal pro-brain natriuretic peptide and angiotensin-converting enzyme-2 levels and their association with postoperative cardiac complications after emergency orthopedic surgery. *Am J Cardiol*. 2012; 109 (9): 1365–1373. DOI: 10.1016/j.amjcard.2011.12.032. PMID: 22381157.
50. *Соколов Д. А., Козлов И. А.* Информативность различных предикторов периоперационных сердечно-сосудистых осложнений в некардиальной хирургии. *Вестник анестезиологии и реаниматологии*. 2023; 20 (2): 6–16. *Sokolov D. A., Kozlov I. A.* Informativeness of various predictors of perioperative cardiovascular complications in non-cardiac surgery. *Messenger of Anesthesiology and Resuscitation = Vestnik Anesthesiologii i Reanimatologii*. 2023; 20 (2): 6–16. (In Russ.). DOI: 10.24884/2078-5658-2022-20-2-6-16.
51. *Fox A. A., Muehlschlegel J. D., Body S. C., Shernan S. K., Liu K. Y., Perry T. E., Aranki S. F., et al.* Comparison of the utility of preoperative versus postoperative B-type natriuretic peptide for predicting hospital length of stay and mortality after primary coronary artery bypass grafting. *Anesthesiology*. 2010; 112 (4): 842–851. DOI: 10.1097/ ALN.0b013e3181d23168. PMID: 20216395.

**Received 13.06.2024**
**Accepted 22.10.2024**