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EARLY POSTOPERATIVE COMPLICATIONS IN OPEN CARDIAC SURGERY. A CURRENT STRATEGY FOR PREDICTION AND RISK STRATIFICATION

THESIS SUMMARY

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CONTENTS

The thesis is presented on 153 pages and is illustrated with 55 tables and 38 figures. The bibliography includes 320 literature sources. The study was conducted at the Cardiac Surgery Clinic at St. Marina University Hospital –Varna. The thesis was discussed and referred for defence at the departmental council of the Department of General and Operative Surgery at the Medical University "Prof. Dr. P. Stoyanov"– Varna.

The thesis defence will take place on ..... 2025 at ..... in the ……. hall ..... at an open session of the Scientific Jury.

FREQUENTLY USED ABBREVIATIONS

CABG – aortocoronary bypass (Coronary Artery Bypass Graft)
AV – aortic valve
GI tract – gastrointestinal tract
ECC – extracorporeal circulation
DM – diabetes mellitus
CHF – congestive heart failure
IS – ischemic stroke
CAD – coronary artery disease
LA – left atrium
MI – myocardial infarction
AKI – acute kidney injury
AFib – atrial fibrillation
SCA – selective coronary angiography
HF – heart failure
TG – triglycerides
TIA – transient ischemic attack
PAD – chronic arterial insufficiency of the extremities (or Peripheral Artery Disease)
Hb - haemoglobin
COPD –chronic obstructive pulmonary disease
AVR – aortic valve replacement
IABP – Intra-aortic balloon pump counterpulsation
LAVI – left atrial volume index
LVEF – left ventricular ejection fraction
MVR – mitral valve replacement
MVr – mitral valve reconstruction
n.a. – not available
OPCAB – off-pump coronary artery bypass (OPCAB) surgery
on-pump CABG - coronary artery bypass surgery with extracorporeal circulation
PCI – percutaneous coronary intervention
sCr – serum creatinine
SPAP – systolic pulmonary artery pressure
STS – Society of Thoracic Surgeons
Ve – mitral flow, Ve (or peak E-wave velocity)
Va – A-wave velocity (peak velocity of blood flow during atrial contraction)

INTRODUCTION

Open cardiac surgery is a significant breakthrough in the management of cardiovascular diseases. Its beginning is associated with unsuccessful attempts and high mortality rates, especially before the introduction of the heart-lung machine into clinical practice. The development of surgical techniques, anaesthesia, resuscitation, and postoperative care has significantly reduced perioperative mortality and complications, shortened hospital stay and improved postoperative quality of life.

Even with the progress in modern cardiology and the development of minimally invasive procedures, having direct access to the heart remains a crucial option for addressing cardiac pathology. The frequency of open cardiovascular operations varies significantly according to a number of factors, such as demographic indicators, geographical location, including the specificity of regional health systems (Epstein et al., 2011; Weisel, 2018). Recent epidemiological data presented by the Society of Thoracic Surgeons (STS) regarding the volume of cardiac operations worldwide show 1.5 million cardiac operations per year or an average of 123.2 (27.3 – 271.5) operations per 100,000 population per year (Vervoort et al., 2023). The volume of CABG surgeries is 36.7 per 100,000 population per year. Aorto-coronary bypass, valve reconstruction and valve replacement, as well as corrections of congenital heart defects, are among the most common operations in open cardiac surgery (Murphy et al., 2015).

The complexity and specificity of open cardiac surgery quite naturally and inevitably determine the risk of complications. Depending on their severity, complications can represent a serious health and social problem for the patient and the healthcare system by prolonging hospital stay, increasing healthcare costs and changing the patient's quality of life in the short or long term. Their most common classification is according to their severity and duration. Depending on their severity, they are defined as mild, moderate, severe and death (Jawitz et al., 2020). According to their temporal characteristics, they are divided into early and late, which has a fundamental aspect on postoperative treatment and follow-up of patients (Wong et al., 2017). Understanding these definitions helps in planning postoperative care, monitoring and the overall approach to the patient, as well as counselling patients about expectations after surgery.

Early postoperative complications represent a significant part of postoperative complications, and about 60% of them occur by the 5th postoperative day (Winkelmann et al., 2015). The multiple pathophysiological mechanisms associated with their manifestation also determine their great diversity (Pahwa et al., 2021). There is no unified system for their classification, but most often they are grouped according to the affected organs and systems, namely: cardiovascular, pulmonary, renal, neurological, gastrointestinal and hepatic. Among them, not least in importance, is bleeding in the early postoperative period (Dyke et al., 2014). Their frequency is largely influenced by the comorbidities of patients, both in the most advanced tech hubs and in those with the least experience and technological capabilities (Gonzalez et al., 2014; Silber et al., 1995; Silber et al., 1992).

Cardiovascular complications after open cardiac surgery are among the most common complications. Among them, rhythm complications have the largest share (up to 70% according to some authors), and atrial fibrillation (AFib) occupies a leading position – up to 40% of all registered rhythm complications (Bessissow et al, 2015). Stroke, in the setting of manifested postoperative AFib, is the most severe complication and determines significant disability and mortality. Cardiac surgery remains associated with significant postoperative bleeding. The frequency of this complication varies according to different registries, but most commonly, data shows a bleeding frequency requiring blood transfusion in over 30% of open cardiac operations. Among neurological complications, stroke remains the most clinically significant complication, with the risk varying between 1% and 5% (Mao et al., 2015; Shah et al., 2021; Wang et al., 2021). Postoperative delirium and cognitive deficit are the most common complications observed in the early postoperative period and can affect more than half of cardiac surgery patients. The frequency of acute kidney injury (AKI) after open cardiac surgery ranges from 8% to 40% (Schanz et al., 2022). The mortality associated with it is not negligibly low, especially when acute dialysis becomes necessary (Hobson et al., 2009). Acute kidney injury remains one of the complications that play a key role in the course of the postoperative period. The reduction in the frequency of postoperative mortality is not at the pace expected. Mortality in the first 30 days after open cardiac surgery remains poorly characterised. A number of factors are related to the frequency of this complication – clinical characteristics, laboratory data, intraoperative indicators and many others, but their role is not fully specified.

Early postoperative complications remain a challenge for both physicians and patients. Their correct prediction will provide the opportunity to choose the most appropriate therapeutic approach. In this regard, numerous models for prediction and stratification have been developed. The EuroSCORE II model and the STS risk assessment scale are well-accepted tools providing the ability to predict postoperative outcomes. There are also many other assessment models specifically targeted at specific postoperative complications (Fleet et al., 2023; Higgins, 1998; Shahian et al., 2004). They are undoubtedly an integral part of decisions regarding clinical and surgical approaches to patients. At the same time, data from clinical practice shows some of their weaknesses, stemming mainly from the great diversity in demographic and clinical presentation of patients, rapid progress in surgical techniques, and the expanding possibilities of minimally invasive surgery. The dynamic nature of cardiovascular diseases necessitates continuous reassessment and validation of these models with the aim of optimisation and adaptation to the specifics of clinical practice. These details are the prerequisite for identifying and acknowledging models with better adaptable predictive capability for assessing the risk of postoperative complications that would refine preoperative decisions. The integration of advanced analytical scores is expected to lead to improvement in patient assessment and approach. This provided the basis for conducting the present study and specified the formulation of its aim.

AIMS AND TASKS

1. AIM

To propose optimal models for defining the risk of early postoperative complications, including atrial fibrillation, significant bleeding, delirium, acute kidney injury and death after open cardiac surgery.

2. TASKS

To achieve the aim, the following tasks were specified:

1. To retrospectively study the perioperative characteristics of patients who underwent open cardiac surgery by analysing preoperative, intraoperative and postoperative indicators.
2. To investigate the predictive value of perioperative characteristics for the occurrence of postoperative atrial fibrillation.
3. To examine the predictive value of perioperative characteristics for significant postoperative bleeding.
4. To study the predictive value of perioperative characteristics for the development of postoperative delirium.
5. To determine the predictive value of perioperative characteristics for the development of postoperative acute kidney injury.
6. To analyse the predictive value of perioperative characteristics for the occurrence of a fatal outcome after open cardiac surgery.

MATERIALS AND METHODS

1. Study design

The study was conducted at the Cardiac Surgery Clinic of St. Marina University Hospital –Varna. Written approval from the Ethics Committee for Scientific Research of Medical University "Prof. Dr. Paraskev Stoyanov" - Varna (131/11.05.2023) and written consent from the Executive Director of St. Marina University Hospital (ref. АД – 3092/10.08.2022) for researchers' access to medical documentation for the purposes of the study were obtained. The approvals are following the requirements of the Declaration of Helsinki (The World Medical Association Declaration of Helsinki, 2008).

By its nature, this is a retrospective cohort (by definition, non-interventional) study. The only source of information for our research was the medical records (case histories) of patients from hospitalisation for cardiac surgery and the electronic hospital system.

The study period included the time from the patient's admission to the department until their discharge or death. Given the stated aim and formulated objectives, it was divided into preoperative period (the period from the moment of hospitalisation until the start of the operative intervention), intraoperative period (the period during surgery) and early postoperative period (the period from completion of the operative intervention until discharge or death), with the latter being defined based on Rosen's established definition of "early and late postoperative period" (Rosen, 2020).

2. Study participants

The subjects the study (the cohort) were all patients hospitalised at the Cardiac Surgery Clinic of St. Marina University Hospital –Varna from March 2017 to March 2020 who underwent open cardiac surgery. For the purposes of the thesis research this type of surgery was defined as: isolated CABG surgery; isolated valve surgery: aortic valve replacement (AVR), mitral valve replacement (MVR), mitral valve repair (MVr), tricuspid reconstruction or replacement; combined surgery (CABG + valve surgery). Excluded from the study were patients who underwent other types of operative intervention not classified as "open cardiac surgery"; patients with aortic dissection, and patients <18 years of age, regardless of the type of intervention.

3. Data collection – approach and analysed indicators

The collected and analysed perioperative indicators were divided into preoperative, intraoperative, and postoperative. At the same time, they were also grouped according to the specificity of the information they carry, presented below (Tables 1, 2, and 3). A total of 120 indicators were analysed for each patient, namely: 64 preoperative indicators, 16 intraoperative indicators and 40 postoperative indicators. Among the preoperative indicators, we included the EuroSCORE II, STS Score for mortality and STS Score for morbidity and mortality. We calculated these score indicators for each patient.

The early postoperative complications of research interest were new-onset AFib, significant bleeding, postoperative delirium, AKI and death. Predictors for their occurrence were sought among the analysed 120 preoperative, intraoperative and postoperative indicators.

Table 1. *Analysed indicators from the preoperative period*

Demographic indicators: Age (years), gender, BMI (kg/m2)
Laboratory indicators tested in peripheral venous blood: Total white blood cell count (10ˆ9/L), haemoglobin (g/L) incl. qualitative assessment of haemoglobin level presented as absence/degree of anaemia, platelet count (10ˆ9/L), urea (mmol/L), creatinine (µmol/L), eGFR (ml/min/1.73 m2) incl. and qualitative assessment of renal function presented as normal function or degree of impairment, hyperproteinaemia, hypoalbuminemia, total cholesterol (mmol/L), triglycerides (mmol/L), ASAT (U/L), ALAT (U/L), total creatine kinase (U/L), creatine kinase MB fraction (U/L), troponin I (TnI ng/mL), TnI >1.5 ng/mL, C-reactive protein (CRP mg/L), K+ level considered as a binary indicator K+ >5.5 mmol/L and K+ <3.5 mmol/L.
Trans-thoracic echocardiography findings: LVEDD (mm), LVESD (mm), EF (%), hypo-, a-, or dyskinesia of the cardiac apex, LA anteroposterior size (mm), aortic regurgitation, peak gradient AoK >60 mmHg, Ve (m/sec), Va (m/sec), mitral regurgitation, pulmonary hypertension >50 mmHg, large pericardial effusion, large pleural effusion
Data from preoperative SCA: Stenosis in branching coronary arteries in CAD
Concomitant diseases, pathological conditions, and medication: Previous heart surgery, acute infectious endocarditis, atrial fibrillation, angina pectoris, HF III-IV functional class, pulmonary congestion/edema, intubated/mechanical ventilation, acute/subacute MI, arterial hypertension, diabetes mellitus, PAD (peripheral arterial disease), COPD, significant carotid stenosis, AIS (ischemic stroke), chronic dialysis, treatment with aspirin, treatment with another antiplatelet agent, treatment with anticoagulant, antithrombotic

treatment (antiplatelet agent/anticoagulant), treatment with nitrate, treatment with diuretic, treatment with insulin, treatment with catecholamine infusion
Calculated morbidity and mortality rates: EuroSCORE II, STS Score for mortality, STS Score for morbidity and mortality

Table 2. *Analysed indicators from the intraoperative period*

Urgency of the operation (elective, urgent, emergency), surgical access (full sternotomy, longitudinal mini-sternotomy, or thoracotomy), type of operation (aortocoronary bypass, valve surgery, combined surgery), ECC On-pump / Off-pump, total duration of surgery (min), number of grafts, number of distal anastomoses, type of cardioplegia (crystalloid, blood), amount of cardioplegia (ml), clamping time (min), repeated clamping, extracorporeal circulation time (ECC time, min), repeat ECC, reperfusion time (min), reperfusion/clamping time >0.3, defibrillation/cardioversion performed

Table 3. *Analysed indicators from the postoperative period*

Laboratory indicators tested in peripheral venous blood: Decrease in haematocrit >20%, increase in urea >20%, increase in creatinine >30%, decrease in eGFR >25%, decrease in total protein >15%, decrease in albumin >15%, increase in ALAT >3 times, increase in ASAT >3 times, increase in CK >3 times, increase in CK-MB >3 times, increase in TnI >5 times, increase in CRP >5 times, decrease in K+ >20%, lactate (mmol/L)
Transesophageal echocardiography indicators: LVEDD (mm), LVESD (mm), EF (%), Ve (m/sec), Va (m/sec), postoperative pericardial effusion
Rhythm disturbances: Postoperative (new-onset) AFib
Data from mechanical ventilation and the respiratory system: Hours to first intubation, reintubation, duration of mechanical ventilation (total hours), prolonged ventilation >24 hours, pneumonia, postoperative pleural effusion, pneumothorax
Neurological status data: Failure to regain consciousness within 24 hours, delirium, postoperative AIS, postoperative cerebral haemorrhage
Data on postoperative blood loss: Acute bleeding from the GI tract, amount of postoperative bleeding up to 12 hours
Other important postoperative data: Delayed sternal closure, inotropic support with at least one medication, presence of IABP, revision, renal replacement therapy, and acute arterial insufficiency

4. Operative techniques

After standard preparation of the operative field, observing the rules of asepsis and antisepsis, operative access was achieved – longitudinal median sternotomy, partial sternotomy or thoracotomy according to the planned operative intervention. In aorto-coronary bypass operations, arterial and venous grafts were prepared. In cardiac surgery using extracorporeal circulation (ECC), the ascending aorta was routinely cannulated; in rarer cases, the aortic arch, femoral or axillary artery. When necessary, access to the aortic valve was performed through transverse or oblique aortotomy, which was closed in two layers with continuous sutures after aortic valve replacement. Access to the mitral valve was achieved through the left atrium or through the right atrium and interatrial septum. Correspondingly, intervention on the tricuspid valve was accomplished after oblique incision of the right atrium. In combined operations, according to the necessary interventions, the following order of the previously described manipulations was most often followed: starting ECC, aortic clamping, cardiac arrest, aortotomy, excision of aortic valve, performing distal anastomoses to coronary vessels, intervention on the mitral valve and closure of the left atrium, implantation of aortic valve prosthesis and closure of the aortotomy, tricuspid valve intervention and closure of the right atrium, aortic unclamping, performing proximal anastomoses of venous grafts to the ascending aorta. After restoration of cardiac activity and an appropriate time for reperfusion, ECC was gradually discontinued, and decannulation was performed in reverse order. After careful haemostasis, the operative access was closed.

5. Echocardiographic methods

Echocardiographic examination of all study participants was performed using a Vivid 7 Pro echocardiographic device. All echocardiographic methods and measurements made with them were according to the recommendations for assessment of cardiac chambers, proposed and described by the European Society of Cardiology and the American Heart Association (Evangelista et al., 2008; Galiuto et al., 2011; Lang et al., 2006).

6. Statistical methods for data processing

The data in this thesis were statistically analysed using the specialised software product STATISTICA 13.3.0, StatSoft Inc., USA. When testing statistical hypotheses, p=0.05 was chosen as the significance level. This is the probability of making a Type I error, namely rejecting the null hypothesis when it is true.

The following statistical methods were applied: descriptive statistics, Student's t-test for two independent samples and regression analysis.

RESULTS AND DISCUSSION

1. Perioperative characteristics of study participants

1.1. Preoperative indicators

The examined preoperative indicators were divided into demographic indicators, laboratory indicators examined in peripheral venous blood, indicators from transthoracic echocardiography, data from preoperative SCA, comorbidities and calculated scores for morbidity and mortality.

Demographic indicators

A total of 504 patients who underwent surgical treatment at the Cardiothoracic Surgery Clinic of St. Marina University Hospital –Varna during the investigated period from March 2017 to March 2020, were included in the study. Of these, 266 patients (52.78%) underwent surgical intervention for aorto-coronary bypass, 145 patients (28.77%) had valve surgery, and the remaining 93 patients (18.45%) had combined surgery (aorto-coronary bypass and valve surgery).

In total, 314 men (62.30% of the total population) and 190 women (37.70% of the total population) were studied. The mean age of patients was 65.81±10.10 years (minimum age 24 years, maximum age 87 years). The mean age of women was 67.43±10.38 years, and of men, 64.82±9.81 years. Their distribution by age decades was as follows: 4 patients aged up to 30 years, 8 patients in the age range 30–39 years, 31 patients in the age range 40-49 years, 91 patients in the age range 50–59 years, 186 patients in the age range 60-69 years, 170 patients in the age range 70-79 years, and 14 patients aged 80 years and over. A total of 188 patients were under 65 years of age, 211 patients were aged between 65 and 74 years, and 105 patients were over 75 years of age. The obtained p-value for the Kolmogorov-Smirnov test was less than 0.05; therefore, the age distribution of patients in the studied sample follows the law of normal (Gaussian) distribution.

Body mass index (BMI) was also analysed as a universal medical-biological indicator. Of the studied patients, 115 had below normal or normal weight (BMI ≤24.9 kg/m²), 186 patients were overweight (BMI 25-29.9 kg/m²), and 203 patients were obese (BMI ≥30 kg/m²).

Laboratory Indicators Studied in Peripheral Venous Blood

A number of laboratory indicators studied preoperatively in the peripheral venous blood of patients were analysed (Table 4).

Table 4. *Standard laboratory indicators, mean values and their standard deviations*

Laboratory indicators	Value
Total leukocyte count (10ˆ9/L)	8.12 ±2.38
Haemoglobin (g/L)	132.72 ±17.49
Platelet count (10^9/L)	250.77 ±80.53
Urea (mmol/L)	7.19 ±3.45
Creatinine (µmol/L)	87.99 ±33.00
eGFR (ml/min/1.73 m²)	75.72 ±25.18
Cr Cl (ml/min)	90.47 ±66.37
Total cholesterol (mmol/L)	5.00 ±1.79
Triglycerides (mmol/L)	1.72 ±1.05
Total protein (g/L)	74.83 ±6.54
Albumin (g/L)	43.90 ±5.95
ALAT (IU/L)	32.69 ±109.44
ASAT (IU/L)	35.16 ±147.13
Total creatine kinase (U/L)	112.82 ±118.29
Creatine kinase - MB (U/L)	16.89 ±16.86
Tn I (ng/mL)	1.89 ±9.09
CRP (mg/L)	13.28 ±24.98
K^+ (mmol/L)	4.08 ±0.51

The significance of anaemic syndrome for the development of early postoperative complications after open heart surgery provided the rationale for dividing the patient population into subgroups according to the severity of anaemic syndrome, defined by the criteria of the European Haematology Association, namely: normal haemoglobin values (men >135 g/L; women >120 g/L); mild anaemia (men 135-100 g/L; women 120-100 g/L); moderate anaemia (<100-80 g/L); severe anaemia (<80-65 g/L); life-threatening anaemia (<65 g/L) (Iolascon et al., 2024) (Table 5). The key role of platelets in haemostasis suggested that participants should also be divided into three subgroups according to their values, namely: patients with normal platelet count (150-450×10⁹/L), patients with thrombocytopenia (platelet count <150×10⁹/L), and patients with thrombocytosis (platelet count >450×10⁹/L) (Table 5). The patient group was also divided according to the degree of renal impairment in accordance with K/DOQI recommendations (National Kidney Foundation,

2002) (Table 5). The number of patients with hyperproteinaemia, hypoalbuminemia, as well as with deviations in the values of ALAT, ASAT, TnI, K^+ and INR was also calculated (Table 5).

Table 5. *Distribution of patients according to deviations in some laboratory indicators important for the purpose of the study*

Laboratory indicators	Number of patients (%)
Haemoglobin	
Haemoglobin values in normal range (m >135 g/L; f >120 g/L)	315 (62.50)
Mild anaemia (m 135-100 g/L; f 120-100 g/L)	168 (33.33)
Moderate anaemia (<100-80 g/L)	21 (4.17)
Severe anaemia (<80-65 g/L)	0
Life-threatening anaemia (<65 g/L)	0
Platelets	
Normal platelet count (150-450x109/L)	465 (92.26)
Thrombocytosis (platelet count >450x109/L)	8 (1.59)
Thrombocytopenia (platelet count <150x109/L)	31 (6.15)
Creatinine clearance	
Normal renal function (CrCl >85 ml/min)	225 (44.64)
Moderately impaired renal function (CrCl 50-85 ml/min)	212 (42.06)
Severe renal impairment (CrCl <50 ml/min)	67 (13.30)
Renal failure requiring renal replacement therapy	0 (0)
Total protein	
Hyperproteinaemia (total protein <40 g/L)	5 (0.9)
Albumin	
Hypoalbuminemia (albumin <25 g/L)	8 (1.6)
ALAT	
ALAT >40 IU/L ALAT >120 IU/L	74 (14.68) 8 (1.59)
ASAT	
ASAT >40 IU/L ASAT >120 IU/L	74 (14.68) 8 (1.59)
Other important laboratory indicators	
Tn I ≥5 times the reference values	50 (9.92)
K^+ >5.5 (mmol/L) K^+ <3.5 (mmol/L)	7 (1.4) 4 (0.79)
INR >1.2	71 (14.09)

Statistical analysis shows that a considerable percentage of patients had anaemic syndrome preoperatively – a total of 189 or 37.50% of all participants. The number of patients with deviations from the normal platelet count was significantly lower, a total of 39 or 7.74% of all patients. The obtained p-value for the Kolmogorov-Smirnov test was less than 0.05, which was statistical

evidence that the studied sample follows the law of normal (Gaussian) distribution of platelet count. The distribution of the studied sample was also normal according to blood creatinine values. The Kolmogorov-Smirnov test allowed the obtained data from the predictive value of these two indicators to be considered statistically reliable.

Transthoracic Echocardiography Indicators

The analysed data from preoperatively performed transthoracic echocardiography are systematised in Tables 6 and 7.

Table 6. *Mean values and standard deviations of some basic transthoracic echocardiography indicators*

Echocardiographic indicators	Value
LVEDD (mm)	51.96 ±7.57
LVESD (mm)	36.74 ±7.42
EF (%)	51.91 ±11.14
LA front-rear size (mm)	45.95 ±7.73
Ve (m/sec)	0.67 ±0.32
Va (m/sec)	0.81 ±0.26

Table 7. *Transthoracic echocardiography data for some important pathological findings*

Echocardiographic indicators	Number of patients (%)
EF value (%) <30%	11 (2.18)
30% – 39%	40 (7.93)
40% – 49%	176 (34.93)
≥ 50%	277 (54.96)
Hypo-, a, or dyskinesia of the cardiac apex	70 (13.89)
Peak gradient across the Ao valve >60 mmHg	111 (22.02)
Severe aortic regurgitation	23 (4.56)
High-grade mitral regurgitation	66 (13.10)
High-grade tricuspid regurgitation	27 (5.36)
Pulmonary arterial hypertension PG >50 mmHg	13 (2.58)
Pericardial effusion	32 (6.35)
Massive pleural effusion	22 (4.37)

Data from preoperative SCA, comorbidities, pathological conditions, medication treatment and risk assessment scores

The coronary status of patients was analysed based on data available from the last coronary angiography (Table 8).

Table 8. *Coronary status of the studied patient population*

Stenosis in branching coronary arteries in CAD	Number of patients (%)
No stenosis in the epicardial vessels	122 (24.21)
Single-vessel coronary artery disease	53 (10.52)
Two-vessel coronary artery disease	66 (13.10)
Three-vessel and multivessel coronary artery disease	235 (46.63)
≥ 90% LM stenosis	28 (5.56)

The patient's comorbidities are among the main determinants of perioperative complications; therefore, these data were carefully collected from the medical documentation available for the thesis research (Table 9).

Table 9. *Comorbidities and/or pathological conditions*

Comorbidities / pathological conditions	Number of patients (%)
Previous heart surgery	6 (1.19)
Infectious endocarditis	23 (4.56)
Active	16 (3.17)
No evidence of activity	7 (1.39)
Atrial fibrillation	94 (18.65)
Paroxysmal	50 (9.92)
Permanent	44 (8.73)
Angina pectoris	373 (74.01)
Stable angina pectoris	165 (32.74)
Unstable angina	208 (41.27)
Clinically evident heart failure	284 (56.35)
NYHA II functional class	70 (13.89)
NYHA III–IV functional class	214 (42.46)
Acute myocardial infarction	53 (10.51)
Without ST elevation	35 (6.94)
With ST elevation	18 (3.57)
Acute myocardial infarction (within <90 days)	18 (3.57)
Arterial hypertension	453 (89.88)
Diabetes mellitus	172 (34.12)

Oral treatment Insulin treatment	130 (25.79) 42 (8.33)
PAD Without necrosis/amputation With necrosis/amputation	42 (8.33) 38 (7.54) 4 (0.79)
COPD	20 (3.97)
Significant carotid stenosis or previous carotid intervention Unilateral Bilateral	23 (4.56) 16 (3.17) 7 (1.39)
Chroniodialysis	0 (0)
Ischemic stroke Chronic (within >14 days) Acute	60 (11.90) 58 (11.51) 2 (0.40)
Pulmonary congestion/oedema preoperatively	40 (7.94)
Intubation / mechanical ventilation	2 (0.40)
Catecholamine support Dopamine infusion Adrenaline infusion	6 (1.19) 4 (0.79) 2 (0.40)
Nitrate r.o./infusion	235 (46.63)
High-dose loop diuretic	250 (49.60)
Insulin treatment s.c./infusion	76 (15.08)

Antithrombotic therapy conducted before surgery was analysed in detail due to its key role in one of the most serious complications in open heart surgery – bleeding (Table 10). EuroSCORE II assessment scores were calculated, as well as STS scores for mortality and morbidity and mortality (Table 11).

Table 10. *Antithrombotic therapy – preoperative data*

Type of medication	Number of patients (%)
Aspirin	238 (47.22)
P2Y12 antiplatelet agent Clopidogrel Ticagrelor Prasugrel	39 (7.74) 28 (5.56) 10 (1.99) 1 (0.20)
Dual antiplatelet therapy (P2Y12 antiplatelet + aspirin) Aspirin + Clopidogrel Aspirin + Ticagrelor Aspirin + Prasugrel	 39 (5.75) 28 (5.56) 10 (1.99) 1 (0.20)
Oral anticoagulant Sintrom	55 (10.91) 28 (5.56)

Xarelto	10 (1.98)
Pradaxa	7 (1.39)
Eliquis	10 (1.98)

Table 11. *Calculated assessment scores for mortality and the combined morbidity and mortality indicator*

Grading scale	Value
EuroSCORE II	2.82±3.13
STS mortality score	2.30±2.81
STS morbidity and mortality score	10.32±8.73

1.2. Intraoperative Indicators

The study included a number of intraoperative indicators representing the specificity of open heart surgery (Table 12).

Table 12. *Intraoperative indicators analysed for the purposes of the study – frequency of distribution and mean values*

Intraoperative indicators	Number of patients (%)
Urgency of the operation	
Elective	370 (73.41)
Non-urgent	103 (20.44)
Urgent	31 (6.15)
Operative access approach	
Complete sternotomy	471 (93.45)
Longitudinal mini-sternotomy	24 (4.76)
Thoracotomy	9 (1.79)
Type of surgery	
CABG	266 (52.78)
Valve surgery	145 (28.77)
Combined surgery	93 (18.45)
ECC On-pump	398 (78.97)
ECC Of-pump	106 (21.03)
Number of grafts	
One graft	52 (10.32)
Two grafts	96 (19.05)
Three or more grafts	211 (42.12)
Number of distal anastomoses	

One distal anastomosis	53 (10.52)
Two distal anastomoses	60 (11.90)
Three or more distal anastomoses	247 (49.01)
Type of cardioplegia	
Crystalloid cardioplegia	383 (75.99)
Blood cardioplegia	10 (1.98)
Repeated clamping	7 (1.39)
Repeat ECC	8 (1.59)
Reperfusion time/clamping time >0.3	360 (71.43)
Defibrillation/cardiac resuscitation	130 (25.79)
Intraoperative indicators	**Value**
Clamping time	78.64±30.14
ECC time	126.20±49.00
Reperfusion time	37.07±17.50
Total duration of surgery (min)	271.60±70.26
Amounts of cardioplegic solution	1295±485

1.3. Postoperative Indicators

The studied postoperative indicators most often represented changes that occurred in a number of indicators after the intervention (Table 13).

Table 13. *Analysed postoperative indicators – frequency among the studied population and mean values*

Postoperative indicators	Number of patients (%)
Haematocrit decrease > 20%	275 (54.56)
Urea increase > 20%	305 (60.52)
Creatinine increase > 30%	189 (37.50)
eGFR decrease > 25%	194 (38.49)
Decrease in total protein >15%	484 (96.03)
Decrease in albumin >15%	400 (79.37)
ALAT increase > 3x	167 (33.13)
ASAT increase > 3x	232 (46.03)
Increase in total creatine kinase > 3x	457 (90.67)
Increase in creatine kinase-MB > 3x	301 (59.72)
Increase in TnI > 5x	312 (61.90)
Increase in CRP > 5x	305 (60.52)
Decrease in K+ > 20%	63 (12.50)
Postoperative pericardial effusion	52 (10.32)

Postoperative atrial fibrillation (new-onset)	98 (19.44)
Repeat intubation	27 (5.36)
Continuous ventilation >24 hours	68 (13.49)
Pneumonia	7 (1.39)
Postoperative pleural effusion	85 (16.87)
Pneumothorax	5 (0.99)
Delayed sternum closure	4 (0.79)
Inotropic support with at least one medication	207 (41.07)
Presence of IABP	25 (4.96)
Revision	8 (1.59)
Renal replacement therapy	4 (0.79)
Failure to regain consciousness by the 24th hour	22 (4.37)
Delirium	122 (24.21)
Postoperative IS	19 (3.77)
Postoperative cerebral haemorrhage	0 (0)
Acute arterial insufficiency	13 (2.58)
Acute bleeding from the GI tract	6 (1.19)
Postoperative indicators	**Value**
Lactate (mmol/L)	4.53±5.41
LVEDD (mm)	50.37±7.13
LVESD (mm)	36.65±8.11
EF (%)	51.10±10.35
Ve (m/sec)	0.88±0.48
Va (m/sec)	0.74±0.31
Hours to first extubation	13.70±24.24
Duration of intubation (total hours)	20.80±64.60

2. Postoperative atrial fibrillation – data modelling of studied perioperative indicators through logistic regression

Most commonly, new-onset AFib as a complication was registered after aorto-coronary bypass surgery. Of the total 98 patients registered with new-onset AFib, 54 patients had undergone CABG surgery, 20 patients – valve surgical intervention, and the remaining 24 patients had undergone combined cardiac surgery. The rhythm disturbance occurred 41.93±8.16 hours postoperatively.

The possibility of predicting the occurrence of new-onset AFib was sought among the total 120 studied indicators – 64 preoperative indicators, 16 intraoperative indicators, and 40 postoperative indicators. The results from univariate logistic regression for each of them are presented in

Appendix No. 1, Tables 1–3. They showed that 18 of them had predictive value for AFib occurrence after open heart surgery, evident from the p-value of the univariate logistic models ($p<0.05$) and the calculated OR. For greater clarity, these 18 indicators were presented independently in the table below (Table 14). The positive values of coefficient B_1 show that with increasing values of the indicators age, LVESD, LA size, SPAP, STS score value for morbidity and mortality, ECC time, reperfusion time, urea, lactate and ventilation hours, as well as in the presence of HF III-IV functional class, reintubation, inotropic support and postoperative delirium, the probability of rhythm disturbance occurrence increases. The negative coefficient B_1 for the indicators preoperative eGFR, preoperative EF, decrease of >15% in total protein and albumin shows an inverse correlation – with their decrease, the probability of rhythm disturbance occurrence increases.

Table 14. *Statistically significant predictors for the occurrence of postoperative (new-onset) atrial fibrillation – assessed coefficients of logistic regression models and p-value of the Wald criterion. Model accuracy*

Indicators	**B_1***	**P* value**	**OR**	**Correctness in case classification**
Preoperative indicators				
Age (years)	0.072	**P<0.05**	12.298	75.52%
eGFR (ml/min/1.73 m^2)	-0.144	**P<0.05**	0.99	73.12%
LVESD (mm)	0.056	**P<0.05**	1.57	84.10%
EF (%)	-0.022	**P<0.05**	0.97	76.12%
LA size (mm)	0.058	**P<0.05**	11.06	76.33%
SPAP > 50 mmHg	0.814	**P<0.05**	2.56	77.03%
HF III-IV functional class	0.514	**P<0.05**	11.90	65.22%
STS mortality and morbidity score	0.152	**P<0.05**	2.014	74.23%
Intraoperative indicators				
ECC time (min)	0.005	**P<0.05**	8.89	73.67%
Reperfusion time (min)	0.023	**P<0.05**	0.95	73.31%
Postoperative indicators				
Urea increase > 20%	0.398	**P<0.05**	3.03	70.06%
Decrease in total protein >15%	-2.896	**P<0.05**	2.25	74.66%
Decrease in albumin >15%	-1.490	**P<0.05**	3.78	69.16%
Lactate (mmol/L)	0.046	**P<0.05**	4.532	74.94%
Re-intubation	1.177	**P<0.05**	3.245	70.71%
Ventilation hours (total)	0.005	**P<0.05**	4.531	74.94%

Inotropic support with at least one medication	0.365	**P<0.05**	4.088	75.26%
Delirium	0.815	**P<0.05**	4.531	74.94%

Notes:
* regression constant (see "Statistical methods for results processing")
** regression coefficient (see "Statistical methods for results processing")
*** Wald statistic has χ^2 distribution and its statistical significance shows whether a given independent variable has (at $p \leq 0.05$) or does not have (at $p > 0.05$) statistically significant participation in the regression equation

Based on the established significant univariate logistic models, a multivariate model was created to test the statistical significance of each of the nineteen factors. In the multivariate model, eight factors retained their significance (Table 15).

Table 15. *Factors in the multivariate logistic model for predicting new-onset atrial fibrillation after open heart surgery*

	Const B0	**Age (years) (X_1)**	**eGFR (J/min/1.73 m^2) (X_2)**	**LA size (mm) (X_3)**	**LVESD (mm) (X_4)**	**ECC time (min) (X_5)**	**Lactate (mmol/L) (X_6)**	**Intubation duration (total hours) (X_7)**	**Delirium (absence/presence) (X_8)**
Estimate	-7.762	0.064	-0.007	0.072	0.058	0.005	0.042	0.003	0.778
St Error	1.784	0.021	0.003	0.030	0.025	0.003	0.023	0.002	0.363
t(275)	-4.350	3.107	-2.267	2.384	2.313	1.648	1.863	1.471	2.145
p-value	0.002	0.002	0.023	0.018	0.021	0.014	0.046	0.046	0.033
-95%CL	-11.27	0.023	-0.014	0.012	0.008	0.009	-0.002	-0.001	0.063
+95%CL	-4.245	0.106	0.031	0.131	0.108	0.019	0.087	0.048	1.493
Wald's Chi-square	18.924	9.655	5.139	5.688	5.351	2.716	3.472	2.166	4.599
p-value	0.001	0.018	0.023	0.017	0.020	0.013	0.062	0.046	0.032
Odds ratio (unit ch)	0.004	1.066	0.992	1.074	1.060	1.105	1.043	1.003	2.178
-95%CL	0.001	1.023	0.985	1.013	1.008	0.999	0.998	0.998	1.065
+95%CL	0.014	1.111	0.999	1.140	1.114	1.211	1.090	1.008	4.451

The created multivariate model is illustrated in the following format (presented below). Substituting it with specific indicator values will allow the calculation of the expected probability for new-onset AFib after open heart surgery in clinical practice. The presented multivariate logistic regression model has an OR 5.123 and high accuracy in case classification, 78.89%.

$$d(x)= = -7.762 + 0.064X_1 – 0.007X_2 + 0.072X_3 + 0.058X_4 + 0.005X_5 + 0.042X_6 + 0.003X_7 + 0.778X_8$$

A variety of studies have been conducted to explore factors that may serve as predictors for postoperative AFib. A large number of indicators from demographic and clinical patient characteristics, laboratory and echocardiographic indicators, etc., have been studied. The data for almost all of them are contradictory. A number of demographic and clinical indicators show a correlation with disease manifestation, such as male gender, obesity, preoperatively known paroxysmal AFib, enlarged left atrial dimensions, reduced left ventricular systolic function, COPD, chronic kidney disease, diabetes mellitus, rheumatic disease, etc. (Fleet et al., 2023; Raiten et al., 2015). Ethnicity shows predictive value in some studies (Banach et al., 2007; Dandale et al., 2014). Elevated BMI (BMI > 35 kg/m²) is associated with postoperative AFib occurrence in some studies, but others completely deny its value (Tan et al., 2015; Magee et al., 2007). The number of transfused blood units, clamping time, as well as other intraoperative indicators, also show predictive power, which sometimes, however, borders on statistical significance (Bramer et al., 2011; Melby et al., 2015; Topal & Eren, 2011; Wong et al., 2014). Quite naturally, many biochemical indicators, such as CRP and leukocyte count, and echocardiographic indicators have also been studied (Fujiwara et al., 2014; Hu et al., 2015; Kang et al., 2018). Cardiovascular risk factors are also characterised by great contradiction in their predictive capabilities (Alexandre et al., 2017; Lin et al, 2018; Selvi et al., 2018). These include arterial hypertension, peripheral vascular disease, hypercholesterolemia, coronary artery disease (CAD), and diabetes mellitus (DM) (Guenancia et al., 2015; Gungor et al., 2011; Ozturk et al., 2019; Worku et al., 2015).

The predictive models for postoperative AFib created to date do not show significant predictive power. Fleet et al. present one of the most extensive and detailed analyses in this direction (Fleet et al., 2023). Of the total 12 models presented, seven are directed entirely toward postoperative AFib. Some of them are not validated, and those that have undergone external validation studies (e.g., the models of El-Chami et al., Silva et al., AFRisk index, and POAF score) show low C-statistics of the models, between 0.594 and 0.766. A considerable part (eight of them) show large deviations when they cannot be accurately calculated. Retrospective analysis of the methods used for data collection provides grounds to believe that there are discrepancies and a lack of standardisation in the way data classification is done, including the ability to exclude already

existing AFib. It is also striking that authors approach selectively by analysing populations with specific intraoperative characteristics, rather than approaching the entire patient population that underwent open heart surgery, a selection that lacks factual justifications. None of the predictive models created to date has good discriminating ability. The indicators that retain their predictive ability for postoperative AFib occurrence in different assessment models are few, and in this sense, the data to date regarding significant predictors for postoperative AFib occurrence are contradictory. The effectiveness of the predictive models built on this information is not very convincing. Our proposed multivariate model has a high accuracy of predicted cases and is a good prerequisite for conducting prospective clinical studies aimed at its validation.

3. Significant postoperative bleeding – probability prediction through logistic regression

Based on the UDPB criteria for defining bleeding, which we adopted for the purposes of our study, 52 patients from the studied population were determined to be patients with significant bleeding, which included severe and massive bleeding (Table 16). By the classifier recommendations, the presence of at least one component of significant bleeding was sufficient to place a patient in this class (Dyke et al., 2014).

Table 16. *Significant bleeding in the studied population – distribution according to UDPB criteria*

Type of significant bleeding	**Number of patients (%)**
Deferred sternum closure	0(0)
Postoperative sternal drain loss >1001 ml in < 12 hours	39 (7.74)
Erythrocytes transfusion > 5 units	9 (1.59)
Transfused fresh-frozen plasma > 5 units	7 (1.19)
rFVIIa application	0 (0)
Re-exploration / tamponade	11 (2.18)

We aimed to identify the possibility of predicting significant bleeding among the studied preoperative and intraoperative indicators (Appendix No. 1, Table 4, Table 5). The values of postoperative indicators were also modelled using logistic regression (Appendix No. 1, Table 6). Considering that they were registered at a time when bleeding was most likely already present, this raises debate about their predictive value – to what extent they are predictors or consequences of bleeding. Therefore, the obtained results regarding the predictive value of postoperative indicators

were analysed carefully and accepted as possible predictors only those measured immediately after the end of cardiac surgery.

From the analysed perioperative indicators, Wald statistics showed significance of 31 indicators (independent variables) in the logistic model (Appendix No. 1, Tables 4-6, $p<0.05$). For 15 of them, the calculated OR values tend toward zero; therefore, we assume that their classifying ability is not well defined. Of the remaining 16 indicators that are statistically significant according to the Wald criterion, 5 indicators are preoperative, 3 indicators are intraoperative, and 8 indicators are postoperative. They are presented below in Table 17.

Table 17. *Statistically significant predictors for postoperative significant bleeding – evaluated coefficients of logistic regression models and p-value of the Wald criterion. Model accuracy*

Indicators	**B_1***	**P* value**	**OR**	**Correctness in case classification**
Preoperative indicators				
Anaemia (Hb <135 g/L in men; Hb <120 g/L in women)	0.055	P<0.05	8.470	86.52
Urea (mmol/L)	0.127	P<0.05	8.840	89.68
Creatinine (µmol/L)	0.011	P<0.05	8.804	89.64
eGFR (ml/min/1.73 m2)	-0.059	P<0.05	26.278	83.56
Antithrombotic treatment (antiaggregant/anticoagulant)	0.611	P<0.05	26.00	86.56
Intraoperative indicators				
Type of surgery	0.012	P<0.05	9.830	88.62
ECC On-pump / Off-pump	0.043	P<0.05	9.068	89.66
ECC time (min)	0.011	P<0.05	10.979	87.63
Postoperative indicators				
Creatinine increase > 30%	0.817	P<0.05	8.4	80.32
Decrease in total protein > 15%	-11.765	P<0.05	21.612	89.90
ALAT increase > 3x	0.013	P<0.05	16.44	85.00
ASAT increase > 3x	0.010	P<0.05	24.50	88.36
Lactate (mmol/L)	0.090	P<0.05	8.15	89.42
Hours to first extubation	0.043	P<0.05	8.111	91.86
Ventilation duration (total hours)	0.008	P<0.05	18.367	90.04
Continuous ventilation >24 hours	0.043	P<0.05	7.152	81.66

* See "Notes" under Table 14

When creating a multivariate logistic model for predicting significant bleeding, postoperative indicators were excluded from it. A reduced regression model was constructed only from independent variables from the preoperative and intraoperative periods. Independent variables from the postoperative period were not included in the logistic analysis. The decision for this was influenced by the retrospective nature of the study, which did not allow us to define the cause-and-effect correlation, as well as because in clinical practice, these indicators are most often predetermined by the bleeding itself.

Based on the statistical significance of the indicators presented in the univariate logistic models, as well as in search of optimal model accuracy from a clinical point of view, a multivariate logistic regression was created with six predictors included in it (Table 18). The created multivariate logistic model has the following form:

$$d(x)= -4.984 + 0.192X_1 - 0.059X_2 + 0.611X_3 + 0.043X_4 + 0.012X_5 + 0.055X_6$$

Table 18. *Predictors for the occurrence of postoperative significant bleeding in the multivariate logistic regression model*

	Const B0	**Preoperative urea value (mmol/L) (X_1)**	**Preoperative eGFR (ml/min/1.73 m2) (X_2)**	**Pre-operative antithrombotic treatment (anaggregant/anticoagulant) (X_3)**	**ECC On-pump/Off-pump (X_4)**	**Type of surgery (X_5)**	**Preoperative anaemia (X_6)**
Estimate	-4.984	0.192	-0.059	0.611	0.043	0.012	0.055
St Error	0.804	0.068	0.011	0.157	0.016	0.003	0.016
t(275)	-6.197	2.817	-5.223	3.892	3.669	4.014	3.358
p-value	0.0002	0.005	0.009	0.001	0.003	0,0001	0.001
-95%CL	-6.568	0.057	-0.082	0.302	0.019	0.006	0.022
+95%CL	-3.399	0.325	-0.037	0.921	0.066	0.019	0.088
Wald's Chi-	38.409	7.935	27.284	15.148	11.346	16.119	11.278

square							
p-value	0.005	0.004	0,0002	0.001	0.004	0.003	0.007
Odds ratio (unit ch)	0.007	1.211	0.943	1.843	1.043	1.012	1.057
-95%CL	0.001	1.059	0.922	1.352	10.019	1.006	1.023
+95%CL	0.033	1.385	0.964	2.511	11.067	1.018	1.092

The regression coefficients in front of the variables show that preoperatively elevated urea values, reduced eGFR, anaemia, as well as antithrombotic treatment, increase the risk of significant postoperative bleeding. Cardiac surgery using extracorporeal circulation (ECC), as well as combined operations (CABG + valve surgery), also defines an increased risk of significant bleeding. Substituting it with specific parameter values will allow the calculation of the expected probability for significant bleeding after open heart surgery in clinical practice. The presented multivariate logistic regression model has an OR of 28.102 and 89.50% accuracy in case classification.

The assessment of published research indicates that risk factors for postoperative mediastinal bleeding after open heart surgery can be divided into three groups. The first group includes patient-related factors. These include advanced age, female gender, small body surface area, preoperative anaemia, advanced heart disease, comorbidities, coagulopathies, etc. The second group includes medications affecting coagulation, such as antiplatelet agents and anticoagulants, whose intake has not been discontinued according to the time for depletion of their action, as well as fibrinolytics before emergency surgery. The third group presents factors related to the surgical intervention itself – complex valve-bypass surgery operations, interventions under deep hypothermia, reoperations, emergency operations (Elassal et al., 2021).

Our results confirm the significance of some indicators, but new ones are also established. The established high predictive value of preoperative urea levels (OR=8.840, accuracy 89.68%), eGFR value (OR=26.278, accuracy 83.56%), and antithrombotic treatment (OR=26.00, accuracy 86.56%) is striking. The significance of the type of surgery and the use of the heart-lung machine is confirmed (Table 32).

The potential to effectively estimate the risk of significant postoperative bleeding would contribute to a more effective approach to patients preoperatively and intraoperatively. The creation of

effective assessment scales for risk evaluation of the complication will have substantial clinical and social effects.

4. Postoperative delirium – prognostic variables and logistic regression models

The observed neurological complications in our studied population are presented in the table below (Table 19). As expected and consistent with the existing information from global research, postoperative delirium is the most common neurological complication after open heart surgery and was observed in 24.21% of patients included in the study.

Table 19. *Neurological disorders registered after surgical intervention*

Neurological disorders	Number of patients (%)
Failure to regain consciousness up to the 24th hour after surgical intervention	22 (4.37)
Postoperative delirium	122 (24.21)
Ischemic stroke	19 (3.77)
Brain haemorrhage	1 (0.20)

We aimed to determine if it was feasible to predict the onset of postoperative delirium after surgery. We analysed preoperative, intraoperative and postoperative indicators through data modelling with logistic regression (Appendix No. 1, Tables 7–9). To provide a clearer perspective on the thesis research, the table below presents only the indicators with statistical significance, calculated OR and correctly classified cases (Table 20). They are a total of 7 out of all studied indicators and provide a good opportunity for predicting postoperative delirium. Their values allow correct diagnosis of over 70% of the observed cases.

Table 20. *Statistically significant predictors for the occurrence of postoperative delirium – evaluated coefficients of logistic regression models and p-value of the Wald criterion. Model accuracy*

Indicators	B_0*	B_1*	P* value	OR	Correctness in case classification
Preoperative indicators					
Age (years)	-5.084	0.060	P<0.05	2.851	73.93

eGFR (ml/min/1.73 m2)	0.287	-0.009	P<0.05	2.851	73.93
Postoperative indicators					
Atrial fibrillation (new onset)	-1.212	0.297	P<0.05	2.340	76.56
Lactate (mmol/L)	-0.787	0.061	P<0.05	22.537	86.98
EF (%)	1.913	-0.065	P<0.05	6.800	77.50
Hours to first extubation	-1.144	0.012	P<0.05	1.339	72.54
Re-ventilation	-1.043	0.888	P<0.05	10.281	72.14

* See "Notes" under Table 14

From the preoperative indicators, only patient age and eGFR showed statistical significance in the univariate logistic models (Appendix No. 1, Table 7; Table 34). With increasing age and decreasing eGFR values, the probability of complication occurrence increases. From the intraoperative indicators, none showed statistically significant predictive value (Appendix No. 1, Table 8). ECC time, as well as the total duration of surgery, showed borderline levels of statistical significance (p=0.052 and p=0.056, respectively) with increasing probability of delirium development as their values increase. From the postoperative indicators, 5 showed statistically significant ability to predict the development of delirium immediately after open heart surgery, namely: lactate values, LV ejection fraction, new-onset AFib after open heart surgery, and duration of ventilation including hours to first extubation and reintubation (Appendix No. 1, Tables 9; Table 20). With increasing lactate values and prolonging hours to first extubation, the probability of postoperative delirium increases. It also increases with the appearance of AFib (new-onset), conducting repeat ventilation, and decreasing LV ejection fraction.

After establishing significant univariate logistic models, a multivariate model was created to assess their simultaneous effect on postoperative delirium (Table 21). The multivariate model included 7 indicators and is represented in the following format:

$$d(x) = -5.788 + 0.068X_1 + 0.006X_2 + 0.011X_3 + 0.678X_4 - 0.074X_5 + 0.052X_6 + 0.748X_7$$

Substitution with specific indicator values and calculation of p(d) will allow calculation of the expected probability for new-onset atrial fibrillation after open heart surgery in clinical practice. The presented multivariate logistic regression model has an OR 5.766 and high accuracy in case classification – 73.99%.

Table 21. *Predictors for postoperative delirium in multivariate logistic regression*

	Const B0	Age (years)(X_1)	eGFR (ml/min/1.73 m^2) (X_2)	Hours of first intubation(X_3)	Re-intubation (X_4)	Postoperative EF (%) (X_5)	Lactate (mmol/L)(X_6)	Postoperative atrial fibrillation (new onset)(X_7)
Estimate	-5.788	0.068	0.006	0.011	0.678	0.074	0.052	0.748
St Error	1.343	0.016	0.041	0.044	0.452	0.008	0.028	1.003
t(275)	-4.307	4.195	-2.163	1.968	2.485	-2.679	0.027	-7.125
p-value	0.002	0.003	0.048	0.047	0.038	0.049	0.047	0.004
-95%CL	-8.429	0.036	-0.003	0.001	0.022	0.029	0.011	0.691
+95%CL	-3.147	0.099	0.086	0.227	1.563	0.052	0.048	1.354
Wald's Chi-square	18.55	17.603	20.026	3.732	12.207	3.820	13.226	35.76
p-value	0.002	0.002	0.048	0.047	0,0373	0.049	0.047	0.004
Odds ratio (unit ch)	0.003	1.070	2.001	17.396	10.960	5.986	20.949	0.385
-95%CL	0.002	1.036	0.992	10.992	0.804	1.971	0.897	0.296
+95%CL	0.043	1.105	2.902	19.536	14.774	7.002	21.005	0.501

The frequency of stroke and neurological complications after open cardiac surgery generally remains unchanged over the years and reaches a concerning 6%, while the frequency of cognitive and neuropsychiatric complications is significantly higher and may exceed 60% in some cardiac centres (Head et al., 2018; Moreyra et al., 2017). Postoperative delirium is a common complication after open heart surgery, with a frequency varying between 11% and 52%, which depends mainly on patient characteristics and assessment methodology (Lin et al., 2012). It is associated with prolonged hospital stay, increased morbidity and mortality (Kirfel et al., 2021). Undoubtedly, the diversity in clinical manifestation of deviations is very large, and no less challenging is their detection and proper classification. The presented multivariate model has high accuracy in predicting postoperative delirium and high OR, which is a prerequisite for good effectiveness in clinical practice.

5. Acute kidney injury – modelling data from the studied perioperative indicators through logistic regression

The postoperative deviations in kidney function of the studied population were assessed using the RIFLE classification system for AKI based on eGFR values (Table 22).

Table 22. *Distribution of patients according to the degree of AKI defined by the RIFLE classification system*

Grading of acute kidney injury	Number of patients (%)
Stage R	242 (48.02)
Stage I	135 (26.79)
Stage F	84 (16.67)

Stage R: Risk of kidney injury; Stage I: Kidney Injury; Stage F: Kidney Failure

The possibility of predicting AKI development investigated in all analysed preoperative, perioperative and postoperative indicators (Appendix No. 1, Tables 10–12). Data from univariate logistic regression show that of the total 120 analysed indicators, 33 prove significant for AKI occurrence (Appendix No. 1, Tables 10–12, $p < 0.05$). The evaluated coefficients and logarithmic curves constructed on them show the tendency of this dependence. However, it is notable that for 15 of the significant indicators, it is not possible to calculate the OR values and correctly classify cases, with the reason most often being an insufficient number of cases in the respective class. We consider the lack of these data as substantially limiting the predictive value of indicators; therefore, the table below presents only those indicators that have well-defined classification ability (Table 23). These are also the predictors that we consider appropriate to be the subject of multivariate logistic analysis. As evident from the values of coefficient B_1, increasing values of EuroSCORE II, STS score for morbidity, STS score for morbidity and mortality, prolongation of operation time, clamp time, ECC time, reperfusion time, hours to first extubation and duration of ventilation are associated with increased probability of AKI occurrence. It increases in the presence of HF III–IV functional class, significant coronary stenosis and failure to regain consciousness at 24 hours after completion of surgery. The probability of its development is also higher with combined cardiac surgery, as well as postoperative elevation of ASAT, ALAT, lactate and postoperative decrease in total protein and albumin.

Table 23. *Statistically significant predictors for postoperative AKI occurrence – evaluated coefficients of logistic regression models and p-value of the Wald criterion. Model accuracy*

Indicators	B_1*	P* value	OR	Correctness in case classification
Preoperative indicators				
HFH III–IV functional class	0.518	P<0.05	9.901	66.78
Significant carotid stenosis	0.376	P<0.05	2.074	73.02
EuroSCORE II	0.121	P<0.05	3.309	73.41
STS mortality score	0.202	P<0.05	4.676	74.35
STS morbidity and mortality score	0.065	P<0.05	6.244	75.20
Intraoperative indicators				
Type of surgery	0.954	P<0.05	4.030	73.81
Total operation time (min)	0.009	P<0.05	7.348	75.55
Clamping time (min)	0.018	P<0.05	2.698	68.27
ECC time (min)	0.014	P<0.05	4.760	71.11
Reperfusion time (min)	0.029	P<0.05	2.883	68.19
Postoperative indicators				
Decrease in total protein > 15%	8.174	P<0.05	9.321	76.19
Decrease in albumin > 15%	3.604	P<0.05	2.877	73.00
ALAT increase > 3x	0.044	P<0.05	13.307	72.33
ASAT increase > 3x	0.042	P<0.05	29.111	72.38
Lactate (mmol/L)	0.192	P<0.05	20.141	79.64
Hours to first extubation	0.148	P<0.05	6.849	77.26
Ventilation duration (total)	0.031	P<0.05	14.283	77.73
Failure to regain consciousness by the 24th hour	2.982	P<0.05	19.730	77.18

* See “Remarks” under Table 14

Every independent variable that has predictive value in univariate logistic analysis should be the subject of analysis in a multivariate regression model. Including the largest possible number of predictors in the multivariate model can lead to large standard errors and inaccurate confidence intervals. Therefore, selection for multivariate regression must be performed in such a way as to remove unnecessary predictors and propose a set of those that will simplify the data and improve predictive accuracy. The selection must be based on two main criteria, namely: the correlation and applicability of the predictor in the research model, as well as the statistical significance of the predictor in the univariate model. Based on this data, we created a multivariate model for predicting AKI after open cardiac surgery with nine independent variables (Table 24). It is represented in the following format:

$$d(x)= = -2.058 + 0.517X_1 + 0.954X_2 + 0.011X_3 + 0.018X_4 + 0.192X_5 + 0.065X_6 + 0.031X_7 + 0.031X_8 + 8.771X_9$$

Table 24. *Statistically significant predictors for postoperative AKI development – data from multivariate logistic regression analysis*

	Const. B_0	**HF III-IV functional class (X_1)**	**Type of surgery(X_2)**	**ECC time (min) (X_3)**	**Clamping time (min) (X_4)**	**Lactate value (mmol/L) (X_5)**	**STS morbidity and mortality score (X_6)**	**Reperfusion time (min) (X_7)**	**Duration of intubation (X_8)**	**Decrease in total protein >15% (X_9)**
Estimate	-2.058	0.517	0.954	0.011	0.018	0.192	0.065	0.031	0.031	8.771
St Error	0.639	0.226	0.133	0.004	0.003	0.028	0.012	0.008	0.006	1.495
t(275)	3.217	-2.289	-7.125	2.778	5.057	6.713	-5.441	3.598	5.113	-5.867
p-value	0.001	0.022	0.004	0.005	0.006	0.001	0.009	0.003	0.004	0.009
-95%CL	0.799	0.072	0.691	0.003	0.011	0.135	-0.088	0.014	0.009	-11.71
+95%CL	3.317	0,972	1.354	0.019	0.025	0.248	-0.041	0.049	0.004	-5.832
Wald's Chi-square	10.35	5.242	50.76	7.722	25.57	45.06	29.60	12.94	20.615	34.42
p-value	0.001	0.022	0.001	0.005	0.006	0.001	0.009	0.003	0.003	0.009
Odds ratio (unit ch)	7.834	0.596	0.385	1.011	10.18	1.211	0.936	1.032	1.032	0.002
-95%CL	2.224	0.381	0.296	1.003	1.011	1.145	0.914	1.014	1.019	0.001
+95%CL	27.59	0.929	0.501	1.019	1.025	1.282	0.959	1.051	1.044	0.002

The probability of AKI after open cardiac surgery increases with preoperatively known HF III–V functional class, when performing combined surgery (CABG + valve intervention) compared to isolated valve or bypass surgery, with prolongation of ECC time, clamping time and reperfusion time, as well as with increasing values of STS score for morbidity and mortality, with increasing postoperative lactate values and decreasing total protein postoperatively. Substitution in the multivariate model with specific values of the nominal indicators and calculation of p(d) will allow the expected probability of AKI after open heart surgery to be calculated in clinical practice. The presented multivariate logistic regression model has an OR of 14.283 and correctness in case classification of 77.86%.

Overall mortality in open cardiac surgery can vary within a wide range due to a number of factors related to patient characteristics, surgical intervention, resuscitation and in-hospital measures. The risk of mortality among the patient population undergoing cardiac surgery significantly increases with the development of acute kidney injury. Severe perioperative disturbances in kidney function have an unfavourable effect on morbidity and mortality in patients in both short-term and long-

term plans. Every decline in eGFR by 10 ml/min is associated with a 14% increase in the risk of death (Blumenfeld et al., 2022; Fernando et al., 2014; Huen et al., 2012; Park et al., 2019; Raddan et al., 2003; Tseng et al., 2020; Wang et al., 2022). One of the most recently published meta-analyses shows high mortality in the long and short term, reaching up to 30% despite the rapidly developing possibilities of modern resuscitation and intensive care (Milne et al., 2022). Cardiac surgery-associated AKI is related to an increased risk of death, which persists even after complete recovery of kidney function.

There is a significant variety in the established predictors for AKI. The proposed systems are not numerous and do not have the desired diagnostic value. In this sense, the outlined multivariate logistic model is an opportunity to achieve a smoother postoperative period and faster recovery of operated patients.

6. Early postoperative mortality – prognostic variables and logistic regression models

A total of 41 deaths were established among the studied patient population. Death was registered on average on the 6^{th} postoperative day (6.38±9.27 days, between the 1^{st} and 50^{th} day), with the highest mortality registered in the first 10 postoperative days (29 patients).

The possibility for mortality prediction was investigated among all indicators analysed in our research – preoperative, intraoperative and postoperative (Appendix No. 1, Tables 13–15). The results from data modelling using univariate logistic regression showed that 49 of the studied indicators present a statistically significant possibility for predicting mortality in the early postoperative period after open cardiac surgery (Appendix No. 1, Tables 13–15). The number of indicators is significantly larger compared to that established for predicting AFib, significant bleeding, delirium and AKI, which we consider quite typical, since fatal outcome is often accompanied or preceded by a number of other complications. For 28 of them, OR cannot be calculated, and their correctness for case classification cannot be determined. The absence of this data limits the predictive value of the indicators. The table below presents only those indicators that have well-defined classification ability and based on which the multivariate model for mortality prediction was built (Table 25). Their number is 21. The high values of OR and the

accuracy of classified cases are impressive, over 90%. Quite expectedly and naturally, our results confirmed the high predictive value of the clinically proven and most accepted models for predicting death after cardiac surgery – EuroScore II and STS score.

Table 25. *Statistically significant predictors for mortality – estimated coefficients of logistic regression models and p-value of the Wald criterion. Model accuracy*

Indicators	B_1*	P* value	OR	Correctness in case classification
Preoperative indicators				
Urea (mmol/L)	0.137	P<0.05	12.297	92.31
Creatine kinase - MB (U/L)	0.013	P<0.05	11.784	92.00
EuroSCORE II	0.290	P<0.05	31.569	92.66
STS mortality score	0.305	P<0.05	15.903	92.05
STS morbidity and mortality score	0.908	P<0.05	10.556	91.65
Intraoperative indicators				
Total duration of the surgery (min)	0.014	P<0.05	64.028	92.64
Amount of cardioplegia (ml)	0.002	P<0.05	10.091	90.32
ECC time (min)	0.021	P<0.05	55.938	91.67
Reperfusion time (min)	0.038	P<0.05	20.171	90.79
Postoperative indicators				
Urea increase > 20%	1.058	P<0.05	36.346	90.82
Creatinine increase >30%	2.167	P<0.05	28.000	87.83
eGFR decrease >25%	11.325	P<0.05	39.111	89.72
Albumin decrease >15%	6.229	P<0.05	9.589	91.00
ASAT increase > 3x	2.115	P<0.05	18.991	91.93
Lactate (mmol/L)	0.194	P<0.05	292.61	96.01
Re-intubation	5.641	P<0.05	281.88	97.08
Ventilation duration (total hours)	2.395	P<0.05	21.857	92.43
Continuous ventilation >24 hours	1.423	P<0.05	24.516	92.64
Presence of IABP	1.231	P<0.05	32.237	92.86
Failure to regain consciousness by the 24th hour	3.887	P<0.05	48.747	93.85
Amount of postoperative bleeding up to the 12th hour	0.002	P<0.05	20.955	92.99

* See "Notes" under Table 14

After establishing the significant univariate logistic models, a multivariate model was created. For this, we established an additional objective – to investigate the possibility of building upon the

established EuroScore II or STS score models. The components of the created multivariate model involving the STS score are presented in the table below (Table 26).

Table 26. *Multivariate regression of statistically significant mortality predictors*

	Const. B0	Pre-operative urea value (mmol/L) (X_1)	Post-operative creatinine >30% (X_2)	ECC time (min) (X_3)	Lactate value (mmol/L) (X_4)	STS mortality score (X_5)	Hours of intubation (total) (X_6)
Estimate	-13.33	0.167	0.027	0.024	0.085	0.013	4.445
St Error	2.631	0.111	0.980	0.008	0.021	0.138	0.641
t(275)	-5.066	1.506	0.028	2.839	4.067	0.037	6.928
p-value	0.001	0.034	0.006	0.005	0.007	0.049	0.001
-95%CL	-18.53	-0.052	0.809	0.007	0,044	-0.286	3.184
+95%CL	8.127	0.387	4.678	0.041	0.127	0.261	5.706
Wald's Chi-square	25.670	2.268	7.840	8.063	16.541	1.879	48.01
p-value	0.004	0.032	0.005	0.004	0.004	0.049	0.001
Odds ratio (unit ch)	0.001	1.182	11.554	1.024	1.089	1.237	85.241
-95%CL	0.009	0.948	2.247	1.007	1.045	0.750	24.164
+95%CL	0.011	1.473	107.5	1.04	1.135	1.998	300.71

The logistic model for predicting death after open cardiac surgery is represented in the following format:

$$d(x) = -13.33 + 0.167X_1 + 0.027X_2 + 0.024X_3 + 0.085X_4 + 0.013X_6 + 4.445X_7$$

Substitution with specific values of the indicators and calculation of p(d) will allow the expected probability of death after open cardiac surgery to be calculated in clinical practice. The presented multivariate logistic regression model has an OR of 152.91 and 96.11% correctness in case classification. The model includes a total of 6 indicators. When examined carefully, it is evident that it represents the STS score with 5 additional indicators added that are not part of it: preoperative urea value, postoperative creatinine increase >3 0%, ECC time, ventilation hours, and postoperative lactate value. They carry additional information regarding the patient's preoperative status, intraoperative and postoperative data. According to statistical analysis data, this increases the correctness of the STS score from 92.05% to 96.11%. Although four of the five indicators are

obtained during and after surgery, the additional information they carry will enable intensification and optimisation of the approach to already operated patients.

7. Concluding Discussion

The creation of predictive models for the risk of complications after open cardiac surgery will enable optimisation of preoperative patient preparation and surgical technique, improvement of prognosis in the postoperative period, as well as patient awareness and their involvement in treatment. At the same time, it will provide an opportunity to evaluate surgical interventions across different medical facilities in an unbiased manner and improve treatment quality programs. Last but not least, it will improve the prediction of hospital indicators such as duration of hospital stay (intensive care unit stay and total hospital stay) and frequency of in-hospital complications, which are part of the objective indicators considered in the allocation of funding sources (Prins et al., 2012).

The summarised analysis of our results provides an opportunity to assess the significance of patient characteristics in their entirety for the development of early postoperative complications. The conducted retrospective study has substantial clinical and scientific value, but also socio-economic aspects, as evidenced by the following facts:

- Open cardiac surgery remains an indispensable and often key part of the modern therapeutic approach to patients with cardiovascular diseases, and the complications we analysed are among the most common after open cardiac surgery.

- The created scales for assessing postoperative risk for a particular complication (except scales for assessing death risk) usually differ significantly in the indicators included in them, and their correctness varies within a very wide range.

- They are often not validated.

- They are usually specifically targeted toward a population with a specific type of surgical intervention.

For us, the significance of the obtained results is predetermined by the design of the study itself, namely:

- 120 indicators from the preoperative, intraoperative and postoperative period were simultaneously studied.

- Some of them were analysed dynamically (before and after surgical intervention), which specifies their participation in the created predictive models.

- A patient population that underwent a wide spectrum of open cardiac surgeries (aortocoronary bypass surgery, valve surgery, combined surgery) was studied. Thus, the proposed predictive models can receive wide clinical application.

- Some of the created multivariate logistic models for risk prediction confirm and build upon widely validated models, which is evidence of the precision of the analysis performed and an objective prerequisite for these models to be validated in large prospective clinical studies.

Early postoperative complications are an extremely important determinant for the success of surgical intervention, survival and quality of life of patients in the short and long term (Winkelmann et al., 2015). Some of these occurrences are relatively common, mainly in the first five postoperative days (Wong et al., 2017). This provides grounds to consider that they are primarily a function of the preoperative, intraoperative and early postoperative characteristics of patients (Gonzalez et al., 2014; Pahwa et al., 2021; Silber et al., 1995). Our research was developed specifically based on these concepts.

We consider the simultaneous analysis of 120 indicators (Tables 1–3) as a highly significant event. They represent the most essential characteristics from the preoperative, intraoperative and postoperative period after open heart surgery. Our literature review did not find another study analysing simultaneously such a large number of indicators, respectively patient characteristics, with such precision and detail.

New-onset AFib is the most common rhythm disturbance after open cardiac surgery (Bessissow et al., 2015). Its high frequency and unclear pathophysiological mechanisms make the possibility of

effective prediction of its occurrence a real challenge. Currently, there is no established and widely used assessment scale in clinical practice (Fleet et al., 2023). One of the probable reasons for this is the fact that most of them are not initially directed toward predicting the rhythm disturbance (Fleet et al., 2023; Segar et al., 2023). The predictors participating in them are most often the usual risk factors for cardiovascular diseases. For the first time in our study, a model includes indicators from the preoperative, intraoperative and postoperative period, for each of which there is direct or indirect evidence of connection with disease manifestation. The preoperative indicators in our model are age, eGFR, LA size and LVESD (Table 14). Age is the least disputed predictor of rhythm disturbance manifestation. Impaired kidney function and increased left atrial and left ventricular dimensions are usually found in patients with AFib (Fleet et al., 2023; Raiten et al., 2015; Shen et al., 2011). The intraoperative indicators are represented by ECC time, and the postoperative ones by ventilation duration. They, as well as the postoperative indicators defined by the logistic model – lactate and delirium manifestation – influence the neurohumoral balance of the organism, haemodynamics and water-electrolyte balance, closely linked to the probability of AFib manifestation. For the first time, an assessment model is presented that combines indicators from different groups, namely: demographic, laboratory, echocardiographic and cardiac resuscitation, which is a prerequisite for objectivity and high specificity.

The frequency of significant bleeding after open cardiac surgery is not negligibly small, as well as the number of blood transfusions performed by necessity (Colson et al., 2016; Elassal et al., 2021; Petricevic et al., 2020). This is one of the prerequisites for it to be the subject of research interest. The assessment models of bleeding risk after open heart surgery presented so far have been created mainly as a result of data analysis from patients who underwent aortocoronary bypass surgery (Biancari et al., Ranucci et al., 2009). Valve and combined surgeries are usually not included in them, unlike our study, as they have their own specificity. Our model, besides the expected preoperative indicators – anaemia, presence of antithrombotic treatment, kidney function (assessed through eGFR value) and urea value, includes key indicators for the course of surgical intervention – type of operation and the participation of extracorporeal circulation in the surgical intervention (Table 17). On-pump surgeries, as well as combined surgeries (valve and bypass surgery), are associated with considerably increased risk of postoperative significant bleeding compared to surgical interventions performed off-pump or only bypass or valve surgery. These data can be of

substantial benefit to the surgeon in choosing their surgical strategy, based on the benefit-risk balance.

The frequency of neurocognitive disorders varies widely, showing both high rates and considerable differences (McPherson et al., 2013). Usually, their assessment is based on questionnaires evaluating the psychoemotional state (Kirfel et al., 2021; Lin et al., 2012). Our presented multivariate model is not only highly accurate in predicting postoperative delirium and has a high OR, which is a prerequisite for good effectiveness in clinical practice. It is based entirely on objective indicators – demographic, clinical and laboratory (Table 21). It includes preoperative, intraoperative and postoperative indicators.

Acute kidney injury after open cardiac surgery is a significant clinical, social and economic problem. It is critical in the postoperative period and requires increased care and costs not only during hospital stay, but often after discharge as well (Bandelac et al., 2022; Olivero et al., 2012). Our presented predictive model includes nine indicators, and it undoubtedly makes an impression that three of them are related to the duration of the surgery itself – ECC time, clamp time and reperfusion time (Table 24). This presents significant rationale for defining surgical time in order to reduce AKI risk and achieve a smoother postoperative period.

Mortality is the most serious complication after open-heart surgery. Despite the great research interest and the multiple scales created for its prediction, it often occurs unexpectedly (Wang et al., 2016; Quin et al., 2011). Our presented multivariate logistic regression model has a very high OR value and correctness in case classification. The model includes 6 indicators: the calculated STS score with 5 additional indicators added that are not part of it – preoperative urea value, postoperative creatinine increase > 30%, ECC time, intubation hours and lactate value (Table 26). They carry additional information regarding the patient's preoperative status, intraoperative data and postoperative data and build upon its correctness for case classification, as evident from the obtained results (Table 25).

The recognised significance of postoperative morbidity as the main determinant of hospital costs and quality of life after surgery initiates research focused on predicting postoperative complications. Creating reliable predictive models for assessing the risk of complications after open cardiac surgery is an opportunity to optimise the approach, care and recovery of patients.

Correct prediction and risk stratification of complications will provide greater security and peace of mind, both for treatment and for the patients and their relatives. The established multiple predictors should be systematised into unified predictive models, which would allow their effective inclusion in the clinical assessment of patients. The necessity for risk prediction in significant postoperative complications is indisputable. Research often indicates that significant risk factors for mortality have no relation to the prediction of postoperative morbidity and mortality. The heterogeneous nature of postoperative morbidity complicates the ability to predict morbidity. Very often, assessment scales are not even created for morbidity assessment, as are the risk assessors EuroSCORE, Parsonnet and Pons assessor. The assessment systems EuroSCORE and STS risk scoring models are undoubtedly established for predicting mortality risk. They have moderate, statistically reliable predictive power regarding mortality in patients after open cardiac surgery, which determines their wide application and acceptance in clinical practice. At the same time, their predictive ability regarding morbidity is lower, most likely because they were not originally created for establishing morbidity risk.

It is reasonable to look for distinct predictors for each specific postoperative complication. Considering the established debates regarding the limitations of the assessment tools developed to date, we conducted our study, aiming to minimise any potential weaknesses of already presented assessment models.

CONCLUSIONS

1. In the present study, significant predictors for early manifestation of atrial fibrillation, significant bleeding, delirium, acute kidney injury and death after open cardiac surgery were established. By their nature, they represent perioperative demographic, laboratory, echocardiographic, clinical or specific intraoperative indicators.
2. Some predictors are presented as a function of time (dynamically), which undoubtedly specifies and strengthens their value.
3. The studied patient population underwent a wide spectrum of open cardiac surgeries, which is an objective prerequisite for the created predictive models to receive wide clinical application.
4. Preoperative kidney function, represented through eGFR value, plays a key role in the early manifestation of atrial fibrillation, significant bleeding, delirium and death, demonstrated by the results of the multivariate logistic models.
5. Mechanical ventilation and extracorporeal circulation are significant factors for the studied early postoperative complications, which is confirmed through results from multivariate and univariate logistic regression.
6. Multivariate logistic models for predicting acute kidney injury and death include the calculated value of the validated assessment scale STS score, which is a straightforward indication of the precision of the study and the conducted analysis.
7. In the predictive multivariate logistic models of the analysed complications, preoperative and intraoperative indicators participate simultaneously, and postoperative indicators are not uncommon either. Correct prediction is a multi-stage process, requiring in-depth knowledge of the patient.

CONTRIBUTIONS

The obtained results have an original clinical character.

1. A first-of-its-kind retrospective clinical study in open cardiac surgery was conducted with simultaneously analysed 120 perioperative indicators for prediction and risk stratification of the most common early postoperative complications – atrial fibrillation, significant bleeding, delirium, acute kidney injury and death.
2. Predictive models calculating the expected probability of manifestation of each complication were created. They are distinguished by very high accuracy in case classification, exceeding 96% prediction of fatal postoperative outcomes.
3. For the first time, an assessment model of the probability for new-onset postoperative AFib is presented, which combines key perioperative indicators, including echocardiographic and cardiac resuscitation indicators.
4. For the first time, a predictive model for postoperative delirium is presented, based entirely on objective measurable indicators, rather than on qualitative assessment through psychoemotional balance indicators.
5. An objective possibility for building upon the predictive value of the validated STS score model for acute kidney injury and death after open cardiac surgery is presented, evident from the high accuracy of the new models.

STUDY LIMITATIONS OUTLINING PERSPECTIVES FOR FUTURE RESEARCH

The study is retrospective, which limits the researcher's control over the collected data. The sole source of information for our study was the patients' medical records. This prevents analysis and use of data that requires clinical correlation for accurate assessment. The findings obtained provide a reliable and compelling basis for further validation in large prospective clinical studies.

THESIS-RELATED PUBLICATIONS

Full-text papers published in non-indexed peer-reviewed journals:

1. **Bachvarov G**. Early postoperative complications in open heart surgery patients: a review. WJARR. 2024;20(2):956-961.
2. Arif S, Brady Z, **Bachvarov G,** Negreva M. Risk factors for early neurological complications after coronary artery bypass graft versus valve replacement surgery: regional cardiac centre study. MRJMMS. 2022;10(12):286-291.

APPENDIX

Table 1. *Predictive value of studied preoperative indicators for manifestation of new-onset atrial fibrillation after open heart surgery – results from univariate logistic regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Age (years)	-5.901	0.072	**P<0.05**	12.298	75.52
Gender	-1.089	0.007	P>0.05		
BMI (kg/m^2)	-1.086	0.386	P>0.05		
Total leukocyte count (10ˆ9/ L)	-1.005	0.014	P>0.05		
Haemoglobin (g/L)	0.713	-0.056	P>0.05		
Anaemia (Hb <135 g/L in men; Hb <120 g/L in women)	-1.255	0.001	P>0.05		
Platelet count (10ˆ9/L)	-2.114	0.090	P>0.05		
Urea (mmol/L)	-1.046	0.378	P>0.05		
Creatinine (μmol/L)	-1.09	0.048	P>0.05		
eGFR (ml/min/1.73 m^2)	0.018	-0.144	**P<0.05**	0.99	73.12
Renal function (norm/degree of impairment)	-1.100	0.750	P>0.05	n.a.	
Hyperproteinaemia			n.a.		
Hypoalbuminemia			n.a.		
Total cholesterol (mmol/L)	-1.390	0.783	P>0.05		
Triglycerides (mmol/L)	-1.334	0.035	P>0.05		
ASAT (U/L)	-0.904	-0.007	P>0.05		
ALAT (U/L)	-1.066	-0.901	P>0.05		
Total creatine kinase (U/L)	-0.897	0.001	P>0.05		
Creatine kinase - MB (U/L)	-0.693	0.027	P>0.05		
Troponin I (ng/mL)	-1.013	0.021	P>0.05		
Troponin I >1.5 ng/mL	-0.915	0.014	P>0.05		
CRP (mg/L)	-1.101	0.204	P>0.05		
K^+ >5.5 mmol/L			n.a.		
K^+ <3.5 mmol/L	6.395	-2.366	P>0.05		
LVEDD (mm)	2.765	1.475	P>00.05		
LVESD (mm)	-3.455	0.056	**P<0.05**	1.57	84.10
EF (%)	0.080	-0.022	**P<0.05**	0.97	76.12
Peak hypo-, a- or dyskinesia			n.a.		
LA size (mm)	-3.858	0.058	**P<0.05**	11.06	76.33
Aortic regurgitation	-1.630	0.394	P>0.05		
Peak gradient AV>60 mmHg			n.a.		
Ve (m/sec)	-1.562	0.588	P>0.05		
Va (m/sec)	-1.526	0.407	P>0.05		

Mitral regurgitation	-1.170	0.036	P>0.05		
SPAP >50 mmHg	-1.177	0.814	**P<0.05**	2.56	77.03
Large pericardial effusion			n.a.		
Large pleural effusion			n.a.		
Stenosis in branching coronary arteries in CAD	-0.776	0114	P>0.05		
Previous heart surgery			n.a.		
Acute infective endocarditis			n.a.		
Atrial fibrillation			n.a.		
Angina pectoris	-2.004	0.067	P>0.05		
HF III–IV functional class	-2.236	0.514	**P<0.05**	11.90	65.22
Pulmonary stasis/oedema			n.a.		
Intubated/assisted ventilation			n.a.		
Acute/subacute MI	-1.143	0.084	P>0.05		
Arterial hypertension	-1.791	0.751	P>0.05		
Diabetes mellitus	-1.072	0.029	P>0.05		
PAD	-1.086	0.020	P>0.05		
COPD	-1.077	0.381	P>0.05		
Significant carotid stenosis	-1.114	0.255	P>0.05		
Ischemic stroke	-1.026	0.544	P>0.05		
Chroniodialysis			n.a.		
Aspirin treatment	-1.072	0.199	P>0.05		
Treatment with another antiaggregant			n.a.		
Anticoagulant treatment	-0.978	1.23	P>0.05		
Antithrombotic treatment (antiaggregant/anticoagulant)	-0.223	0.947	P>0.05		
Nitrate treatment	-1.060	0.037	P>0.05		
Diuretic treatment	-1.161	0.157	P>0.05		
Insulin therapy			P>0.05		
Catecholamine infusion			n.a.		
EuroSCORE II	2.126	-0.101	P>0.05		
STS mortality score	-1.406	0.152	P<0.05	n.a.	
STS morbidity and mortality score	-1.404	0.033	**P<0.05**	2.014	74.23

Notes:

* regression constant (see "Statistical methods for processing results")

** regression coefficient (see "Statistical methods for processing results")

*** Wald statistic has $\chi 2$ distribution and its statistical significance shows whether a given independent variable has (at $p \leq 0.05$) or does not have (at $p > 0.05$) statistically significant participation in the regression equation

Table 2. *Predictive value of studied intraoperative indicators for the occurrence of new-onset atrial fibrillation after open cardiac surgery – results from logistic univariate regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Urgency of the operation	-9.987	0.112	P>0.05		
Operational access/approach	-0.900	0.170	P>0.05		
Type of surgery	-1.553	0.286	P>0.05		
ECC On-pump / Off-pump	-0.997	-0.077	P>0.05		
Total operation time (min)	-1.954	0.003	P>0.05		
Number of grafts	-0.590	0.345	P>0.05		
Number of distal anastomoses	-1.077	0.560	P>0.05		
Type of cardioplegia	-1.238	-0.017	P>0.05		
Amount of cardioplegia (ml)	0.745	-0.098	P>0.05		
Clamping time (min)	-1.717	0.009	P>0.05		
Repeated clapping			n.a.		
ECC time (min)	-1.722	0.005	**P<0.05**	8.89	73.67
Repeat ECC			n.a.		
Reperfusion time (min)	-1.924	0.023	**P<0.05**	0.95	73.31
Reperfusion/clamping time >0.3	2.134	-0.27	P>0.0.5		
Defibrillation/cardioversion	-1.954	0.023	P>0.0.5		

* See "Notes" under Table 1 of the Appendix

Table 3. *Predictive value of studied postoperative indicators for the occurrence of new-onset atrial fibrillation after open cardiac surgery – results from logistic univariate regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Haematocrit decrease >20%	-2.550	3.932	P>0.05		
Urea increase >20%	-1.543	0.398	**P<0.05**	3.03	70.06
Creatinine increase >30 %	-0.588	0.551	P>0.05		
Decline in eGFR >25%	-0.233	1.260	P>0.05		
Decrease in total protein >15%	0.813	-2.896	**P<0.05**	2.25	74.66
Decrease in albumin >15%	-0.133	-1.490	**P<0.05**	3.78	69.16
ALAT increase > 3x	-0.661	0.001	P>0.05		
ASAT increase > 3x	-0.795	0.001	P>0.05		
Increase in total creatine kinase > 3x	-1.144	0.003	P>0.05		

Increase in creatine kinase-MB > 3x	-1.248	0.019	P>0.05		
Increase in TnI > 5x	-0.979	0.001	P>0.05		
CRP increase > 5x	-1.021	0.005	P>0.05		
Decrease in K+ >20%	-0.219	0.025	P>0.05		
Lactate (mmol/L)	-1.282	0.046	**P<0.05**	4.532	74.94
LVEDD (mm)	-0.990	0.005	P>0.05		
LVESD (mm)	-1.634	0.006	P>0.05		
EF (%)	-0.091	-0.023	P>0.05		
Ve (m/sec)	-1.415	-0.052	P>0.05		
Va (m/sec)	-1.419	-0.890	P>0.05		
Postoperative pericardial effusion			n.a.		
Postoperative atrial fibrillation (new-onset)			n.a.		
Hours of first intubation	-1.087	-0.894	P>0.05		
Re-intubation	-1.176	1.177	**P<0.05**	3.245	70.71
Intubation duration (total hours)	-1.183	0.005	**P<0.05**	4.531	74.94
Continuous ventilation >24 hours	-1.099	0.098	P>0.05		
Pneumonia			n.a.		
Postoperative pleural effusion	-0.620	0.261	P>0.05		
Pneumothorax			n.a.		
Deferred sternum closure			n.a.		
Inotropic support with at least one medication	-1.283	0.365	**P<0.05**	4.088	75.26
Presence of IABP			n.a.		
Revision			n.a.		
Renal replacement therapy			n.a.		
Failure to regain consciousness by the 24th hour			n.a.		
Delirium	-1.296	0.815	**P<0.05**	4.531	74.94
Post-operative ischemic stroke			n.a.		
Postoperative cerebral haemorrhage			n.a.		
Acute arterial insufficiency			n.a.		
Acute bleeding from the GI tract			n.a.		
Amount of postoperative bleeding up to the 12th hour	-1.116	-0.015	P>0.05		

* See "Notes" under Table 1 of the Appendix

Table 4. *Predictive value of studied preoperative indicators for the occurrence of significant bleeding after open cardiac surgery – results from logistic univariate regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Age (years)	-3.205	0.016	P>0.05		
Gender	-2.457	0.444	P>0.05		
BMI (kg/m^2)	-0.657	-0.053	P>0.05		
Total leukocyte count (10ˆ9/ L)	-2.150	0.017	P>0.05		
Haemoglobin (g/L)	0.263	-0.019	P>0.05		
Anaemia (Hb <135 g/L in men; Hb <120 g/L in women)	-2.433	0.055	**P<0.05**	8.470	86.52
Platelet count (10ˆ9/L)	-0.064	-0.09	P<0.05	n.a.	
Urea (mmol/L)	-3.156	0.127	**P<0.05**	8.840	89.68
Creatinine (µmol/L)	-3.215	0.011	**P<0.05**	8.804	89.64
eGFR (ml/min/1.73 m^2)	2.589	-0.059	**P<0.05**	26.278	83.56
Renal function (norm/degree of impairment)	-2.534	0.481	P<0.05	n.a.	
Hyperproteinaemia			n.a.		
Hypoalbuminemia			n.a.		
Total cholesterol (mmol/L)	-1.603	-0.151	P>0.05		
Triglycerides (mmol/L)	-0.980	0.156	P>0.05		
ASAT (U/L)	-2.179	0.596	P>0.05		
ALAT (U/L)	-2.164	0.167	P>0.05		
Total creatine kinase (U/L)	-2.021	-0.002	P>0.05		
Creatine kinase - MB (U/L)	-2.231	-0.001	P>0.05		
Troponin I (ng/mL)	-2.239	-0.238	P>0.05		
Troponin I >1.5 ng/mL	-1.164	0.011	P>0.05		
CRP (mg/L)	-2.102	-0.907	P>0.05		
K^+ >5.5 mmol/L			n.a.		
K^+ <3.5 mmol/L			n.a.		
LVEDD (mm)	-2.378	-0.004	P>0.05		
LVESD (mm)	-4.875	0.062	P>0.05		
EF (%)	-1.787	0.702	P>0.05		
Peak hypo-, a- or dyskinesia	-0.960	0.050	P>0.05		
LA size (mm)	-0.460	-0.062	P>0.05		
Aortic regurgitation			n.a.		
Peak gradient AV>60 mmHg			n.a.		
Ve (m/sec)	-0.987	0.015	P>0.05		
Va (m/sec)	-1.560	0.740	P>0.05		
Mitral regurgitation			n.a.		
SPAP >50 mmHg	-5.201	0.065	P<0.05	n.a.	
Large pericardial effusion			n.a.		
Large pleural effusion	-2.319	0.753	P<0.05	n.a.	

Stenosis in branching coronary arteries in CAD			n.a.		
Previous heart surgery			n.a.		
Acute infective endocarditis	-2.273	0.856	P<0.05	n.a.	
Atrial fibrillation	-3.013	0.198	P>0.05		
Angina pectoris	-1.813	-0.316	P>0.05		
HF III–IV functional class	-3.645	0.655	P>0.05		
Pulmonary stasis/oedema			n.a.		
Intubated/assisted ventilation			n.a.		
Acute/subacute MI	-2.077	-0.157	P>0.05		
Arterial hypertension	-2.001	-0.176	P>0.05		
Diabetes mellitus	-2.153	-0.020	P>0.05		
PAD	-2.205	0.388	P>0.05		
COPD	-2.227	1.064	P>0.05		
Significant carotid stenosis	-2.191	0.237	P>0.05		
Ischemic stroke	-1.176	0.108	P>0.05		
Chroniodialysis			n.a.		
Aspirin treatment			n.a.		
Treatment with another antiaggregant			n.a.		
Anticoagulant treatment			n.a.		
Antithrombotic treatment (antiaggregant/anticoagulant)	-3.066	0.611	**P<0.05**	26.00	86.56
Nitrate treatment	-1.732	-0.128	P>0.05		
Diuretic treatment	-3.011	1.114	P<0.05	n.a.	
Insulin therapy	-2.084	-0.558	P>0.05		
Catecholamine infusion			n. a.		
EuroSCORE II	-1.283	0.479	P>0.05		
STS mortality score	-0.739	0.291	P>0.05		
STS morbidity and mortality score	-2.314	0.830	P>0.05		

* See "Notes" under Table 1 of the Appendix

Table 5. *Predictive value of studied intraoperative indicators for the occurrence of significant bleeding after open cardiac surgery – results from logistic univariate regression*

Indicator tested	**B_0***	**B_1****	**P*** value**	**OR**	**Correctness in case classification**
Urgency of the operation					
Operational access/approach	-1.837	-0.305	P>0.05		
Type of surgery	-4.303	0.012	**P<0.05**	9.830	88.62
ECC On-pump / Off-pump	-2.097	0.043	**P<0.05**	9.068	89.66
Total operation time (min)	-4.573	0.008	P<0.05	n.a.	

Number of grafts	-1.274	-0.499	P<0.05	n.a.	
Number of distal anastomoses	-1.441	-0.366	P<0.05	n.a.	
Type of cardioplegia	-3.420	1.403	P<0.05	n.a.	
Amount of cardioplegia (ml)	-3.478	0.001	P<0.05	n.a.	
Clamping time (min)	-3.245	0.016	P<0.05	n.a.	
Repeated clapping			n.a.		
ECC time (min)	-3.432	0.011	**P<0.05**	10.979	87.63
Repeat ECC			n.a.		
Reperfusion time (min)	-2.335	0.103	P>0.05		
Reperfusion/clamping time > 0.3	-1.396	-0.837	P>0.0.5		
Defibrillation/cardioversion			n.a.		

* See "Notes" under Table 1 of the Appendix

Table 6. *Predictive value of studied postoperative indicators for significant bleeding after open cardiac surgery – results from logistic univariate regression*

Indicator tested	**B_0***	**B_1****	**P*** value**	**OR**	**Correctness in case classification**
Haematocrit decrease >20%			n.a.		
Urea increase >20%			n.a.		
Creatinine increase >30 %	-2.950	0.817	**P<0.05**	8.4	80.32
Decline in eGFR >25%	1.448	-5.034	P<0.05	n.a.	
Decrease in total protein >15%	5.120	-11.765	**P<0.05**	21.612	89.90
Decrease in albumin >15%	0.029	-3.203	P<0.05	n.a.	
ALAT increase > 3x	-2.105	0.013	**P<0.05**	16.44	85.00
ASAT increase > 3x	-2.268	0.010	**P<0.05**	24.50	88.36
Increase in total creatine kinase > 3x			n.a.		
Increase in creatine kinase-MB > 3x			n.a.		
Increase in TnI > 5x	-2.392	0.003	P<0.05	n.a.	
CRP increase > 5x	-2.349	0.002	P>0.05		
Decrease in K+ >20%			n.a.		
Lactate (mmol/L)	-2.737	0.090	**P<0.05**	8.15	89.42
LVEDD (mm)	-1.033	0.014	P>0.05		
LVESD (mm)	-2.020	0.793	P>0.05		
EF (%)	2.214	-0.987	P>0.05		
Ve (m/sec)	2.015	-0.616	P>0.05		
Va (m/sec)	1.089	-0.960	P>0.05		
Postoperative pericardial effusion			n.a.		

Postoperative atrial fibrillation (new-onset)			n.a.		
Hours of first intubation	-3.130	0.043	**P<0.05**	8.111	91.86
Re-intubation			n.a.		
Intubation duration (total hours)	-2.383	0.008	**P<0.05**	18.367	90.04
Continuous ventilation >24 hours	-1.720	0.043	**P<0.05**	7.152	81.66
Pneumonia			n.a.		
Postoperative pleural effusion			n.a.		
Pneumothorax			n.a.		
Deferred sternum closure			n.a.		
Inotropic support with at least one medication	-2.842	1.406	P>0.05		
Presence of IABP			n.a.		
Revision			n.a.		
Renal replacement therapy			n.a.		
Failure to regain consciousness by the 24th hour			n.a.		
Delirium			n.a.		
Post-operative ischemic stroke			n.a.		
Postoperative brain haemorrhage			n.a.		
Acute arterial insufficiency			n.a.		
Acute bleeding from the GI tract			n.a.		
Amount of postoperative bleeding up to the 12th hour			n.a.		

* See "Notes" under Table 1 of the Appendix

Table 7. *Predictive value of studied preoperative indicators for the occurrence of delirium after open cardiac surgery – results from logistic univariate regression*

Indicator tested	**B_0***	**B_1****	**P*** value**	**OR**	**Correctness in case classification**
Age (years)	-5.084	0.060	**P<0.05**	2.851	73.93
Gender	-0.949	0.150	P>0.05		
BMI (kg/m^2)	-0.876	0.008	P>0.05		
Total leukocyte count (10^9/ L)	-1.102	0.200	P>0.05		
Haemoglobin (g/L)	0.320	-0.180	P>0.05		
Anaemia (Hb <135 g/L in men; Hb <120 g/L in women)	-1.111	0.142	P>0.05		

Platelet count (10ˆ9/L)	-0.972	0.018	P>0.05		
Urea (mmol/L)	-0.043	0.421	P>0.05		
Creatinine (µmol/L)	-1.122	0.562	P>0.05		
eGFR (ml/min/1.73 m^2)	0.287	-0.009	**P<0.05**	2.851	73.93
Renal function (norm/degree of impairment)	0.870	-0.030	P>0.05		
Hyperproteinaemia			n.a.		
Hypoalbuminemia			n.a.		
Total cholesterol (mmol/L)	-0.860	0.734	P>0.05		
Triglycerides (mmol/L)	-0.156	1.230	P>0.05		
ASAT (U/L)	-0.801	-0.007	P>0.05		
ALAT (U/L)	-0.995	-0.404	P>0.05		
Total creatine kinase (U/L)	-0.996	0.001	P>0.05		
Creatine kinase - MB (U/L)	-1.097	0.005	P>0.05		
Troponin I (ng/mL)	-0.980	0.034	P>0.05		
Troponin I >1.5 ng/mL	-0.952	0.005	P>0.05		
CRP (mg/L)	-1.035	-0.003	P>0.05		
K^+ >5.5 mmol/L	-0.924	-0.027	P>0.05		
K^+ <3.5 mmol/L	1.052	1.241	P>0.05		
LVEDD (mm)	-0.925	-0.002	P>0.05		
LVESD (mm)	-1.092	0.598	P>0.05		
EF (%)	-0.569	-0.009	P>0.05		
Peak hypo-, a- or dyskinesia			n.a.		
LA size (mm)	1.234	0.071	P>0.05		
Aortic regurgitation			n.a.		
Peak gradient AV>60 mmHg			n.a.		
Ve (m/sec)	-0.976	0.412	P>0.05		
Va (m/sec)	-1.302	0.516	P>0.05		
Mitral regurgitation			n.a.		
SPAP >50 mmHg	-0.995	0.578	P>0.05		
Large pericardial effusion			n.a.		
Large pleural effusion			n.a.		
Stenosis in branching coronary arteries in CAD	-0.600	0.980	P>0.05		
Previous heart surgery			n.a.		
Acute infective endocarditis			n.a.		
Atrial fibrillation	-1.105	0.163	P>0.05		
Angina pectoris			P>0.05		
HF III–IV functional class	-1.546	0.162	P>0.05		
Pulmonary stasis/edema			n.a.		
Intubated/assisted ventilation			n.a.		
Acute/subacute MI	-0.92	0.082	P>0.05		
Arterial hypertension	-1.417	0.407	P>0.05		
Diabetes mellitus	-1.105	0.143	P>0.05		
PAD	-1.055	0.130	P>0.05		

COPD	-1.066	0.527	P>0.05		
Significant carotid stenosis	-1.050	0.077	P>0.05		
Ischemic stroke	-1.091	0.371	P>0.05		
Chroniodialysis			n.a.		
Aspirin treatment	0.900	-1.117	P>0.05		
Treatment with another antiaggregant	0.640	-1.112	P>0.05		
Anticoagulant treatment	0.765	-0.912	P>0.05		
Antithrombotic treatment (antiaggregant/anticoagulant)	0.570	-1.24	P>0.05		
Nitrate treatment	-1.178	0.220	P>0.05		
Diuretic treatment	-1.019	-0.054	P>0.05		
Insulin therapy			n.a.		
Catecholamine infusion			n. a.		
EuroSCORE II	-1.145	0.036	P>0.05		
STS mortality score	-1.048	0.002	P>0.05		
STS morbidity and mortality score	-1.258	0.020	P>0.05		

* See "Notes" under Table 1 of the Appendix

Table 8. *Predictive value of studied intraoperative indicators for the occurrence of delirium after open cardiac surgery – results from logistic univariate regression*

Indicator tested	**B_0***	**B_1****	**P*** value**	**OR**	**Correctness in case classification**
Urgency of the operation	-1.239	0.780	P>0.05		
Operational access/approach	-1.155	0.104	P>0.05		
Type of surgery	-0.884	-0.096	P>0.05		
ECC On-pump / Off-pump	-1.238	-0.161	P>0.05		
Total operation time (min)	-0.697	0.019	P>0.05 (P=0.056)		
Number of grafts	0.780	-0.034	P>0.05		
Number of distal anastomoses	1.230	-1.200	P>0.05		
Type of cardioplegia	0.638	-0.531	P>0.05		
Amount of cardioplegia (ml)	0.987	-0.234	P>0.05		
Clamping time (min)	-1.030	-0.881	P>0.05		
Repeated clapping			n.a.		
ECC time (min)	-1.062	0.175	P>0.05 (P=0.052)		
Repeat ECC			n.a.		
Reperfusion time (min)	-1.326	0.006	P>0.05		
Reperfusion/clamping time > 0.3	-1.423	0.583	P>0.0.5		
Defibrillation/cardioversion	-1.038	-0.163	P>0.0.5		

* See "Notes" under Table 1 of the Appendix

Table 9. *Predictive value of studied postoperative indicators for the occurrence of delirium after open cardiac surgery – results from logistic univariate regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Haematocrit decrease >20%	0.115	-1.874	P>0.05		
Urea increase >20%	-4.310	-0.139	P>0.05		
Creatinine increase >30 %	0.580	-0.710	P>0.05		
Decline in eGFR >25%					
Decrease in total protein >15%	-0.253	2.252	P>0.05		
Decrease in albumin >15%	-1.126	-1.143	P>0.05		
ALAT increase > 3x	0.724	-0.070	P>0.05		
ASAT increase > 3x	-0.645	0.188	P>0.05		
Increase in total creatine kinase > 3x	-2.212	0.100	P>0.05		
Increase in creatine kinase-MB > 3x	-0.966	0.118	P>0.05		
Increase in TnI > 5x	-1.103	0.050	P>0.05		
CRP increase > 5x	-1.612	0.450	P>0.05		
Decrease in K+ >20%	1.117	0.824	P>0.05		
Lactate (mmol/L)	-0.787	0.061	**P<0.05**	22.537	86.98
LVEDD (mm)	-1.193	0.019	P>0.05		
LVESD (mm)	-1.245	0.012	P>0.05		
EF (%)	1.913	-0.065	**P<0.05**	6.800	77.50
Ve (m/sec)	-1.332	-0.101	P>0.05		
Va (m/sec)	-1.512	-0.705	P>0.05		
Postoperative pericardial effusion			n.a.		
Postoperative atrial fibrillation (new-onset)	-1.212	0.297	**P<0.05**	2.340	76.56
Hours of first intubation	-1.144	0.012	**P<0.05**	1.339	72.54
Re-intubation	-1.043	0.888	**P<0.05**	10.281	72.14
Intubation duration (total hours)	-1.047	0.215	**P<0.05**	n.a.	
Continuous ventilation >24 hours	-1.072	0.716	**P<0.05**	n.a.	
Pneumonia			n.a.		
Postoperative pleural effusion	-0.397	0.613	P>0.05		
Pneumothorax			n.a.		
Deferred sternum closure			n.a.		

Inotropic support with at least one medication	-1.210	0.428	P>0.05		
Presence of IABP			n.a.		
Revision			n.a.		
Renal replacement therapy			n.a.		
Failure to regain consciousness by the 24th hour			n.a.		
Delirium			n.a.		
Post-operative ischemic stroke			n.a.		
Postoperative brain haemorrhage			n.a.		
Acute arterial insufficiency			n.a.		
Acute bleeding from the GI tract			n.a.		
Amount of postoperative bleeding up to the 12th hour			n.a.		

* See "Notes" under Table 1 of the Appendix

Table 10. *Predictive value of studied preoperative indicators for the occurrence of AKI after open cardiac surgery – results from logistic univariate regression*

Indicator tested	**B_0***	**B_1****	**P*** value**	**OR**	**Correctness in case classification**	**Indicator tested**
Age (years)		2.157	-0.167	P>0.05		
Gender		0.897	0.175	P>0.05		
BMI (kg/m^2)		1.283	-0.009	P>0.05		
Total leukocyte count (10^9/L)		0.988	-0.123	P>0.05		
Haemoglobin (g/L)		-0.154	0.011	P>0.05		
Anaemia (Hb <135 g/L in men; Hb <120 g/L in women)		1.092	-0.209	P>0.05		
Platelet count (10^9/L)		0.216	0.003	P>0.05		
Urea (mmol/L)		-1.376	0.076	P>0.05		
Creatinine (µmol/L)				n.a.		
eGFR (ml/min/1.73 m^2)				n.a.		

Renal function (norm/degree of impairment)				n.a.		
Hyperproteinaemia		0.992	-0.586	P>0.05		
Hypoalbuminemia		1.043	-1.022	P>0.05		
Total cholesterol (mmol/L)		0.986	-0.200	P>0.05		
Triglycerides (mmol/L)		-0.987	0.432	P>0.05		
ASAT (U/L)		1.058	-0.016	P>0.05		
ALAT (U/L)		1.151	-0.005	P>0.05		
Total creatine kinase (U/L)		1.068	-0.987	P>0.05		
Creatine kinase - MB (U/L)		1.071	0.678	P>0.05		
Troponin I (ng/mL)		0.650	-0.213	P>0.05		
Troponin I >1.5 ng/mL		1.086	-0.20	P>0.05		
CRP (mg/L)		1.002	0.076	P>0.05		
K^+ >5.5 mmol/L		0.913	0.017	P>0.05		
K^+ <3.5 mmol/L		0.908	-0.225	P>0.05		
LVEDD (mm)		1.680	-0.213	P>0.05		
LVESD (mm)		1.603	-0.015	P>0.05		
EF (%)		0.308	-0.019	P>0.05		
Peak hypo-, a- or dyskinesia				n.a.		
LA size (mm)		0.156	-0.001	P>0.05		
Aortic regurgitation		-1.655	0.987	P>0.05		
Peak gradient AV>60 mmHg		0.769	-0.731	P>0.05		
Ve (m/sec)		-1.001	0.056	P>0.05		
Va (m/sec)		-1.227	0.009	P>0.05		
Mitral regurgitation		2.001	-0.590	P>0.05		
SPAP >50 mmHg		-1.122	0.607	P<0.05	n.a.	

Large pericardial effusion		-1.057	0.689	P<0.05	n.a.	
Large pleural effusion		1.037	-0.244	P>0.05		
Stenosis in branching coronary arteries in CAD		-0.106	0.160	P>0.05		
Previous heart surgery		1.002	-0.384	P>0.05		
Acute infective endocarditis		1.205	-0.334	P>0.05		
Atrial fibrillation		1.459	-0.433	P>0.05		
Angina pectoris		0.593	0.336	P<0.05	n.a.	
HF III–IV functional class		-2.059	0.518	**P<0.05**	9.901	66.78
Pulmonary stasis/oedema				n.a.		
Intubated/assisted ventilation				n.a.		
Acute/subacute MI		0.859	0.282	P<0.05	n.a.	
Arterial hypertension		0.794	0.232	P>0.05		
Diabetes mellitus		1.204	-0.177	P>0.05		
PAD		1.004	-0.106	P>0.05		
COPD		1.046	-0.789	P>0.05		
Significant carotid stenosis		-1.051	0.376	**P<0.05**	2.074	73.02
Ischemic stroke		0.983	0.193	P>0.05		
Chroniodialysis				n.a.		
Aspirin treatment		0.744	0.600	P<0.05	n.a.	
Treatment with another antiaggregant		0.971	0.239	P>0.05		
Anticoagulant treatment		1.066	-0.184	P>0.05		
Antithrombotic treatment (antiaggregant/anticoagulant)						
Nitrate treatment		0.678	0.653	P<0.05	n.a.	
Diuretic treatment		1.391	-0.590	P<0.05	n.a.	
Insulin therapy		0.939	0.433	P>0.05		
Catecholamine infusion				n.a.		
EuroSCORE II		-1.377	0.121	**P<0.05**	3.309	73.41
STS mortality score		-1.511	0.202	**P<0.05**	4.676	74.35

STS morbidity and mortality score		-1.747	0.065	**P<0.05**	6.243	75.20

* See "Notes" under Table 1 of the Appendix

Table 11. *Predictive value of studied intraoperative indicators for the occurrence of AKI after open cardiac surgery – results from logistic univariate regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Urgency of the operation	-1.007	0.943	P>0.05		
Operational access/approach	0.980	0.022	P>0.05		
Type of surgery	-2.722	0.954	**P<0.05**	4.030	73.81
ECC On-pump / Off-pump	-1.121	1.875	P<0.05	n.a.	
Total operation time (min)	-3.742	0.009	**P<0.05**	7.348	75.55
Number of grafts	0.854	-0.123	P>0.05		
Number of distal anastomoses	0.723	-0.149	P>0.05		
Type of cardioplegia			n.a.		
Amount of cardioplegia (ml)	0.144	0.365	P>0.05		
Clamping time (min)	-2.208	0.018	**P<0.05**	2.698	68.27
Repeated clapping			n.a.		
ECC time (min)	-2.624	0.014	**P<0.05**	4.760	71.11
Repeat ECC	0.738	0.067	P>0.05		
Reperfusion time (min)	-1.893	0.029	**P<0.05**	2.883	68.19
Reperfusion/clamping time > 0.3	1.909	-0.62	P>0.05		
Defibrillation/cardioversion	0.658	0.154	P>0.05		

* See "Notes" under Table 1 of the Appendix

Table 12. *Predictive value of studied postoperative indicators for the occurrence of AKI after open cardiac surgery – results from logistic univariate regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Haematocrit decrease >20%	-1.019	3.274	P>0.05		
Urea increase >20%			n.a.		
Creatinine increase >30 %			n.a.		
Decline in eGFR >25%			n.a.		
Decrease in total protein >15%	-4.305	8.174	**P<0.05**	9.321	76.19
Decrease in albumin >15%	-1.294	3.604	**P<0.05**	2.877	73.00

ALAT increase > 3x	-0.931	0.044	**P<0.05**	13.307	72.33
ASAT increase > 3x	-0.978	0.042	**P<0.05**	29.111	72.38
Increase in total creatine kinase > 3x	-0.988	0.088	P<0.05	n.a.	
Increase in creatine kinase-MB > 3x	-0.566	0.043	P<0.05	n.a.	
Increase in TnI > 5x	-0.876	0.776	P<0.05	n.a.	
CRP increase > 5x	1.690	0.918	P>0.05		
Decrease in K+ >20%			n.a.		
Lactate (mmol/L)	-1.982	0.192	**P<0.05**	20.141	79.64
LVEDD (mm)	1.520	-0.111	P>0.05		
LVESD (mm)	1.495	0.903	P>0.05		
EF (%)	-0.123	0.023	P<0.05	n.a.	
Ve (m/sec)	0.480	-0.590	P>0.05		
Va (m/sec)	0.897	-0.700	P>0.05		
Postoperative pericardial effusion	0.778	-0.410	P>0.05		
Postoperative atrial fibrillation (new-onset)	-0.908	0.642	P>0.05		
Hours of first intubation	-1.419	0.148	**P<0.05**	6.849	77.26
Re-intubation			n.a.		
Intubation duration (total hours)	-1.633	0.031	**P<0.05**	14.283	77.73
Continuous ventilation >24 hours			n.a.		
Pneumonia			n.a.		
Postoperative pleural effusion	1.114	-0.396	P>0.05		
Pneumothorax	1.014	-0.282	P>0.05		
Deferred sternum closure			n.a.		
Inotropic support with at least one medication	-1.266	0.359	P<0.05	n.a.	
Presence of IABP	-1.102	0.648	P<0.05	n.a.	
Revision			n.a.		
Renal replacement therapy			n.a.		
Failure to regain consciousness by the 24th hour	-1.191	2.982	**P<0.05**	19.730	77.18
Delirium	-1.112	3.450	P>0.05		
Post-operative ischemic stroke	-1.032	1.255	P>0.05		
Postoperative brain haemorrhage			n.a.		
Acute arterial insufficiency			n.a.		
Acute bleeding from the GI tract			n.a.		

Amount of postoperative bleeding up to the 12th hour	-1.366	0.334	P<0.05	n.a.	

* See "Notes" under Table 1 of the Appendix

Table 13. *Predictive value of studied preoperative indicators for the occurrence of death after open cardiac surgery – results from logistic univariate regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Age (years)	-5.099	0.040	P<0.05		
Gender	2.257	0.281	P>0.05		
BMI (kg/m^2)	-1.531	0.031	P>0.05		
Total leukocyte count (10ˆ9/ L)	-0.987	0.092	P>0.05		
Haemoglobin (g/L)	0.527	-0.023	P<0.05	n.a.	
Anaemia (Hb <135 g/L in men; Hb <120 g/L in women)	-2.337	0.639	P<0.05	n.a.	
Platelet count (10ˆ9/L)	-2.286	0.001	P>0.05		
Urea (mmol/L)	-3.572	0.137	**P<0.05**	12.297	92.31
Creatinine (µmol/L)	-1.516	0.078	P<0.05	n.a.	
eGFR (ml/min/1.73 m^2)	-0.091	0.017	P<0.05	n.a.	
Renal function (norm/degree of impairment)	-3.132	0.825	P<0.05	n.a.	
Hyperproteinaemia			n.a.		
Hypoalbuminemia			n.a.		
Total cholesterol (mmol/L)	-2.366	0.441	P>0.05		
Triglycerides (mmol/L)	-1.234	0.019	P>0.05		
ASAT (U/L)	-2.709	0.006	P>0.05		
ALAT (U/L)	-2.653	0.005	P<0.05	n.a.	
Total creatine kinase (U/L)	-1.715	0.523	P>0.05		
Creatine kinase - MB (U/L)	-2.692	0.013	**P<0.05**	11.784	92.00
Troponin I (ng/mL)	-0.988	0.014	P>0.05		
Troponin I >1.5 ng/mL	-2.542	0.031	P>0.05		
CRP (mg/L)	-2.511	0.004	P>0.05		
K^+ >5.5 mmol/L	-2.540	0.311	P>0.05		
K^+ <3.5 mmol/L	1.128	-0.025	P>0.05		
LVEDD (mm)	-2.946	0.016	P>0.05		
LVESD (mm)	-3.144	0.076	P>0.05		
EF (%)	1.976	-0.453	P>0.05		
Peak hypo-, a- or dyskinesia			n.a.		
LA size (mm)	-1.015	0.076	P>0.05		
Aortic regurgitation	-1.786	0.087	P>0.05		
Peak gradient AV>60 mmHg			n.a.		
Ve (m/sec)	-0.956	-0.016	P>0.05		

Va (m/sec)	-1.002	0.319	P>0.05		
Mitral regurgitation			n.a.		
SPAP >50 mmHg	-4.665	0.058	P<0.05	n.a.	
Large pericardial effusion	-2.556	1.201	P<0.05	n.a.	
Large pleural effusion	-2.554	0.601	P>0.05		
Stenosis in branching coronary arteries in CAD	-2.525	0.505	P>0.05		
Previous heart surgery	-1.456	0.743	P>0.05		
Acute infective endocarditis			n.a.		
Atrial fibrillation	-2.613	0.415	P<0.05	n.a.	
Angina pectoris	-2.352	0.062	P<0.05	n.a.	
HF III–IV functional class	-5.397	1.141	P<0.05	n.a.	
Pulmonary stasis/oedema			n.a.		
Intubated/assisted ventilation			n.a.		
Acute/subacute MI	-22.448	14.929	P<0.05	n.a.	
Arterial hypertension	-2.001	-0.496	P>0.05		
Diabetes mellitus	-2.518	0.203	P>0.05		
PAD	-2.552	0.919	P<0.05	n.a.	
COPD			n.a.		
Significant carotid stenosis	-2.545	0.686	P<0.05	n.a.	
Ischemic stroke			n.a.		
Chroniodialysis			n.a.		
Aspirin treatment	-2.311	0.254	P>0.05		
Treatment with another antiaggregant	-1.413	0.481	P>0.05		
Anticoagulant treatment	-0.470	0.511	P>0.05		
Antithrombotic treatment (antiaggregant/anticoagulant)	-0.982	0.250	P>0.05		
Nitrate treatment	-2.321	0.186	P>0.05		
Diuretic treatment	-3.261	0.801	P<0.05	n.a.	
Insulin therapy	-2.496	0.396	P>0.05		
Catecholamine infusion	-1.889	0.144	P<0.05	n.a.	
EuroSCORE II	-3.539	0.290	**P<0.05**	31.569	92.66
STS mortality score	-3.369	0.305	**P<0.05**	15.903	92.05
STS morbidity and mortality score	-3.637	0.908	**P<0.05**	10.556	91.65

* See "Notes" under Table 1 of the Appendix

Table 14. *Predictive value of studied intraoperative indicators for the occurrence of death after open cardiac surgery – results from logistic univariate regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Urgency of the operation	-1.445	0.772	P>0.05		
Operational access/approach	-2.311	0.105	P>0.05		
Type of surgery	-3.795	0.741	P<0.05	n.a.	
ECC On-pump / Off-pump	-1.317	0.906	P>0.05		
Total operation time (min)	-6.662	0.014	**P<0.05**	64.028	92.64
Number of grafts	-2.227	0.076	P>0.05		
Number of distal anastomoses	-2.169	0.079	P>0.05		
Type of cardioplegia	-3.226	0.964	P<0.05	n.a.	
Amount of cardioplegia (ml)	-4.985	0.002	**P<0.05**	10.091	90.32
Clamping time (min)	-4.398	0.024	P<0.05	n.a.	
Repeated clapping			n.a.		
ECC time (min)	-5.213	0.021	**P<0.05**	55.938	91.67
Repeat ECC	-3.242	0.562	P>0.05		
Reperfusion time (min)	-3.902	0.038	**P<0.05**	20.171	90.79
Reperfusion/clamping time > 0.3	-2.471	0.042	P<0.05	n.a.	
Defibrillation/cardioversion	-2.179	0.304	P>0.05		

* See "Notes" under Table 1 of the Appendix

Table 15. *Predictive value of studied postoperative indicators for the occurrence of death after open cardiac surgery – results from logistic univariate regression*

Indicator tested	B_0*	B_1**	P*** value	OR	Correctness in case classification
Haematocrit decrease >20%	-1.411	1.721	P>0.05		
Urea increase >20%	-4.453	1.058	**P<0.05**	36.346	90.82
Creatinine increase >30 %	-5.884	2.167	**P<0.05**	28.000	87.83
Decline in eGFR >25%	-4.481	11.325	**P<0.05**	39.111	89.72
Decrease in total protein >15%	-11.074	2.259	P<0.05	n.a.	
Decrease in albumin >15%	-1.285	6.229	**P<0.05**	9.589	91.00
ALAT increase > 3x	-2.795	3.519	P<0.05	n.a.	
ASAT increase > 3x	-2.934	2.115	**P<0.05**	18.991	91.93
Increase in total creatine kinase > 3x			n.a.		

Increase in creatine kinase-MB > 3x			n.a.		
Increase in TnI > 5x	-2.928	0.004	P<0.05	n.a.	
CRP increase > 5x			n.a.		
Decrease in K+ >20%			n.a.		
Lactate (mmol/L)	-3.870	0.194	**P<0.05**	292.61	96.01
LVEDD (mm)	-2.727	0.142	P>0.05		
LVESD (mm)	-0.358	0.051	P>0.05		
EF (%)	-1.232	0.066	P>0.05		
Ve (m/sec)	-1.222	0.789	P>0.05		
Va (m/sec)	-0.569	-0.014	P>0.05		
Postoperative pericardial effusion			n.a.		
Postoperative atrial fibrillation (new-onset)			n.a		
Hours of first intubation	-3.436	0.008	P>0.05		
Re-intubation	-5.418	5.641	**P<0.05**	281.88	97.08
Intubation duration (total hours)	-3.070	0.029	**P<0.05**	21.857	92.43
Continuous ventilation >24 hours	-3.025	1.423	**P<0.05**	24.516	92.64
Pneumonia			n.a.		
Postoperative pleural effusion	-2.576	0.478	P<0.05	n.a.	
Pneumothorax			n.a.		
Deferred sternum closure			n.a.		
Inotropic support with at least one medication	-5.007	3.357	P<0.05	n.a.	
Presence of IABP	-2.786	1.231	**P<0.05**	32.237	92.86
Revision			n.a.		
Renal replacement therapy			n.a.		
Failure to regain consciousness by the 24th hour	-2.906	3.887	**P<0.05**	48.747	93.85
Delirium			n.a.		
Post-operative ischemic stroke			n.a.		
Postoperative brain haemorrhage			n.a.		
Acute arterial insufficiency			n.a.		
Acute bleeding from the GI tract			n.a.		
Amount of postoperative bleeding up to the 12th hour	-3.921	0.002	**P<0.05**	20.955	92.99

* See "Notes" under Table 1 of the Appendix