Perioperative stroke and survival in coronary artery bypass grafting patients: a SWEDEHEART study

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Abstract

OBJECTIVES: Perioperative stroke is a severe complication of cardiac surgery. We assessed the incidence of stroke over time, the association between stroke and mortality and identified preoperative factors independently associated with perioperative stroke, in a large nationwide cardiac surgery population.

METHODS: All patients who underwent coronary artery bypass grafting in Sweden 2006–2017 were included in a registry-based observational cohort study based on prospectively collected data. Multivariable logistic and Cox regression models were used to assess

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associations between perioperative stroke and mortality and to identify factors associated with stroke. The median follow-up was 6 years (range 0–12).

RESULTS: There were 441 perioperative strokes in 36,898 patients. The mean incidence was 1.2% and decreased marginally over time [adjusted odds ratio (OR) 0.97 per year (95% confidence interval 0.94–1.00), P = 0.035]. Stroke patients had a higher overall mortality risk during follow-up [adjusted hazard ratio 2.30 (2.00–2.64), P < 0.001], with the highest risk during the first 30 postoperative days [adjusted hazard ratio 7.29 (5.58–9.54), P < 0.001]. The strongest independent preoperative factors associated with stroke were prior cardiac surgery [adjusted OR 2.89 (1.40–5.96)], critical preoperative condition [adjusted OR 2.55 (1.73–3.76)], previous stroke [adjusted OR 1.77 (1.35–2.33)], preoperative angina requiring intravenous nitrates [adjusted OR 1.67 (1.28–2.17)], peripheral vascular disease [OR 1.63 (1.25–2.13)] and advanced age [OR 1.05 (1.03–1.06) per year].

CONCLUSIONS: The incidence of perioperative stroke after coronary artery bypass grafting has remained stable. Patients with perioperative stroke had a markedly higher adjusted risk of death early after surgery. The risk declined over time but remained higher during the entire follow-up period.

Keywords: Coronary artery bypass grafting • Perioperative stroke • Incidence • Mortality

ABBREVIATIONS

aHR Adjusted hazard ratio
CABG Coronary artery bypass grafting
CHA2DS-VAS Congestive heart failure, Hypertension, Age ≥ 75 years Diabetes mellitus, previous Stroke or transient ischemic attack Vascular disease, Age 65–74 years, Sex category female
CI Confidence interval
HR Hazard ratio
ICD International Statistical Classification of Diseases system
OR Odds ratio
SWEDHEART Swedish Web System for Enhancement and Development of Evidence-Based care in Heart disease Evaluated According to Recommended Therapies

INTRODUCTION

Perioperative stroke is one of the most devastating complications in cardiac surgery. The incidence of perioperative stroke varies in different studies depending on the study population and stroke definition. In large registry-based studies, the incidence of perioperative stroke varies in mixed cardiac surgery populations from 1.6% to 4.6% and in coronary artery bypass grafting (CABG) patients from 1.1% to 5.7% [1–7]. A recent meta-analysis of mixed cardiac surgery patients reported an incidence of 2.0% [5].

While several studies have reported on the strong association between perioperative stroke and early mortality after cardiac surgery [8, 9], there is less information about the association between perioperative stroke and long-term mortality risk in cardiac surgery patients. Furthermore, most previous investigations on the subject are either limited in size and/or by single-centre design. Likewise, studies on preoperative factors associated with perioperative stroke are attributed to the same limitations. Hence, in the present population-based study, based on a large whole nationwide cohort with complete long-term follow-up, our objectives were to assess the incidence of perioperative stroke over time, identify preoperative factors independently associated with perioperative stroke and assess the association between stroke and short- and long-term mortality.

METHODS

Ethics statement

The study was approved by the Regional Ethics Committee in Gothenburg, Sweden (registration number 139-16 approved 4 April 2016). The Ethics Committee waived individual patient consent due to the registry-based study design. The study was performed in accordance with the 1975 Declaration of Helsinki. Before the analysis, all personal identifiers were replaced by codes to ensure anonymity.

Data availability statement

The data underlying this article were provided by the Swedish Web System for Enhancement and Development of Evidence-Based care in Heart disease Evaluated According to Recommended Therapies (SWEDHEART) and national healthcare registries in Sweden. Data will be shared on request to the corresponding author with permission of SWEDHEART and The National Board of Health and Welfare.

Study design and study population

In this nationwide, population-based cohort study, the study population was identified in the Swedish Heart Surgery Registry, which is a part of the SWEDHEART registry [11]. All patients >18 years who underwent isolated CABG in Sweden from 1 January 2006 until 31 December 2017 were included. Patients who died on the day of surgery were excluded due to uncertain diagnosis of intraoperative stroke. Also, patients who had missing data for perioperative stroke in the registry were excluded. Patients who emigrated during the follow-up period were censored at the time of emigration. The manuscript has been composed according to recommendations in the Strengthening the Reporting of Observational Studies in Epidemiology statement [10].

Data sources and definitions

Data from 3 national registers were merged through the personal social security number, unique for all Swedish citizens. The SWEDHEART registry has a national coverage of 99% [11] and...
contains information about pre-, intra- and postoperative clinical information for all patients who have undergone cardiac surgery in Sweden since 1992. Perioperative stroke is defined in the SWEDHEART registry as any focal neurological deficit occurring postoperatively, during the index hospitalization, and lasting >72 h. The diagnosis in the registry is based on clinical symptoms and does not necessarily require confirmation with imaging studies. The European System for Cardiac Operative Risk Evaluation I definitions were used for critical preoperative status and unstable angina [12].

Diagnosis for the patients’ medical history, other than in the SWEDHEART registry, was retrieved from The National Patient Register. Registration of principal and contributory diagnoses for all hospitalizations in Sweden is mandatory. The registry has complete national coverage for all hospitalized patients since 1987 with a validity of 85–95% [13]. The International Statistical Classification of Diseases system (ICD) was used to identify the diagnoses: ICD 9 for the period 1987–1997 and ICD 10 for the period 1997–2017 (Supplementary Material, Table S1). Information about mortality was collected from the national Cause of Death register [14], which has information on the date and cause of death of all deceased Swedish citizens.

Statistical analyses

Descriptive continuous variables are presented by mean and standard deviation and categorical variables by frequencies and percentages. For comparison between 2 groups, Fisher’s exact test (lowest one-sided P-value multiplied by 2) was used for dichotomous variables.

Univariable and multivariable logistic regression models were used to study the annual trends of the incidence of perioperative stroke and to identify factors associated with perioperative stroke. The full adjustment of the annual trends included age, sex, previous ischaemic stroke, previous transient ischaemic attack, previous haemorrhagic stroke, previous myocardial infarction, diabetes, heart failure, hypertension, atrial fibrillation, renal failure, peripheral vascular disease, history of cancer, chronic respiratory disease, acute coronary syndrome, previous heart surgery and angina at rest. Factors with a P-value of <0.05 in the univariable model were considered for inclusion in the multivariable model using backward selection. Age and sex were forced into the multivariable logistic model. Odds ratio (OR) with 95% confidence interval (CI) are presented from the logistic regression models. Interaction between sex and following variables was studied post hoc: age (<70 and >70 years), previous stroke, preoperative critical state and previous heart surgery.

The change in incidence of perioperative stroke over calendar time was assumed to be linear and tested using logistic regression. Hosmer–Lemeshow test was performed to test goodness-of-fit.

Cox regression models were used to compare mortality, between patients diagnosed with perioperative stroke and those with no perioperative stroke, within 30 days and beyond 30 days, which was divided into 3 time periods, 30 days to 1 year, 1 year to 5 years and >5 years. An overall estimate of HR for the whole time period was presented for completeness and should be interpreted as a mean HR over the studied time. The proportional hazards assumption was investigated by studying the interaction between the status of the perioperative stroke and log(follow-up time), which was found not to be satisfied for the periods 0–30 days and 30 days to 1 year. Further time splitting was therefore performed as follows: 0–7 days, 7 days to 30 days, 30 days to 3 months and 3 months to 1 year. Hazard ratio (HR) with 95% CI were presented from the Cox regression models. Survival probability was presented using the Kaplan–Meier technique.

All tests were two-sided and a P-value <0.05 was considered significant. All analyses were performed by using SAS Software version 9.4 (SAS Institute Inc., Cary, NC, USA).

RESULTS

Patients

A total of 37 173 patients underwent isolated CABG in Sweden during the study period. After exclusion of patients who died during the operation day (n = 48, 0.1%) and patients with missing information about perioperative stroke (n = 227, 0.6%), a total of 36 898 patients were included in the study. Out of these, 173 patients (0.47%) emigrated during follow-up and were censored at the time of emigration. Perioperative stroke occurred in 441 patients (1.2%). The stroke population was older, more likely to be female, and had a higher burden of comorbidities, including e.g. diabetes, previous stroke and peripheral artery disease, than the non-stroke group. The post hoc analyses revealed a significant interaction between sex and age category (P = 0.049) with larger difference in relative odds for female versus male in <70-year-old patients [OR 2.05 (95% CI 1.40–3.00)] than in >70-year-old patients [OR 1.30 (95% CI 1.01–1.66)]. No significant interaction was observed for previous stroke, preoperative critical state and previous heart surgery. Stroke patients had also higher logistic European System for Cardiac Operative Risk Evaluation I and CHA2DS2-VASC score. Patient characteristics in the stroke and no-stroke groups are presented in Table 1. The median follow-up was 6.0 years (range 0–12).

Incidence of stroke over time

The mean annual incidence of perioperative stroke was 1.2%. The annual incidence varied during the study period between 0.6% and 1.7% (Fig. 1). In the unadjusted and age-and-sex only adjusted logistic regression models, there was no significant change in the incidence of perioperative stroke over time [OR 0.98 (95% CI 0.96–1.01), P = 0.17 and 0.98 (95% CI 0.96–1.01), P = 0.19, respectively]. In the multi-adjusted model, there was a statistically significant but marginal reduction in the incidence of perioperative stroke over time [adjusted OR: 0.97 (95% CI 0.94–1.00), P = 0.035] (Hosmer–Lemeshow goodness-of-fit test P = 0.17).

Preoperative factors independently associated with perioperative stroke

Preoperative factors independently associated with stroke are presented with ORs in Table 2. Prior to cardiac surgery, critical preoperative condition, previous stroke, angina at rest requiring intravenous nitrates, peripheral vascular disease, heart failure, female sex, atrial fibrillation, diabetes and age were independently associated with an increased risk for perioperative stroke.
Associations between stroke and all-cause mortality

**Early mortality.** Unadjusted mortality during the first postoperative 30 days was 16.3% (72/441) in the stroke group and 1.3% (455/36 457) in the no-stroke group ($P<0.001$), Table 3. After multi-adjustment, the HR for mortality in stroke patients was 7.29 (95% CI 5.58–9.54), $P<0.001$. For the period from 30 days to 1 year, the unadjusted mortality was 12.6% (40/329) vs 1.8% (639/35 401) and the adjusted HR (aHR) 3.67 (95% CI 2.61–5.15) ($P<0.001$), Table 3. The proportional hazards assumption was not fulfilled for these 2 intervals, and $P$-values for interaction with time were 0.0024 and <0.0001, respectively. To study change in HR over time, analyses were performed for the following time periods: first 7 days, aHR 4.40 (95% CI 2.70–7.17), 7–30 days, aHR 9.96 (95% CI 7.22–13.74), 30 days to 3 months, aHR 6.91 (95% CI 4.43–10.78) and 3 months to 1 year, aHR 2.01 (95% CI 1.15–3.49).

**Mid-term and long-term mortality.** During the total follow-up period, including both early and late mortality, 224/
441 (50.8%) of the stroke patients and 6990/36 457 (19.5%) of the no-stroke patients died. The cumulative mortality in stroke and no-stroke patients is depicted in Fig. 2. Stroke patients had a higher overall mortality risk, including both early and late mortality, during follow-up [aHR 2.30 (95% CI 2.00–2.64), P < 0.001].

For the period 1–5 years postoperatively, the unadjusted mortality was 13.1% (38/291) in the stroke group and 7.7% (2 530/32 871)

### Table 2: Factors associated with perioperative stroke in univariable and multivariable logistic regression models

| Variable                              | Number of strokes (%) | Univariable analysis OR (95% CI) | P-Value | Multivariable analysis OR (95% CI) | P-Value |
|---------------------------------------|-----------------------|----------------------------------|---------|-----------------------------------|---------|
| Sex, n (%)                            |                       |                                  |         |                                   |         |
| Male                                  | 315 (1.1)             | 1.63 (1.33–2.01)                 | <0.001  | 1.39 (1.12–1.72)                  | 0.003   |
| Female                                | 126 (1.7)             | 1.06 (1.04–1.07)                 | <0.001  | 1.05 (1.03–1.06)                  | <0.001  |
| Age (years), mean ± SD                | Stroke group: 72.2 ± 7.6 | 1.00 (0.98–1.03)                | 0.81    |                                   |         |
|                                       | No-stroke group: 74.4 ± 4.2 | 0.96 (0.79–1.17)                | 0.71    |                                   |         |
| Body mass index (kg/m²), mean ± SD    | Stroke group: 27.5 ± 4.2 | 1.45 (1.18–1.77)                | <0.001  |                                   |         |
|                                       | No-stroke group: 27.4 ± 3.2 | 1.14 (1.01–1.29)                | <0.001  |                                   |         |
| Hyperlipidaemia, n (%)                | Yes                   | 1.41 (1.16–1.72)                | <0.001  | 1.28 (1.04–1.56)                  | 0.019   |
|                                       | No                    | 2.35 (1.80–3.07)                | <0.001  | 1.77 (1.35–2.33)                  | <0.001  |
| Hypertension, n (%)                   | Yes                   | 2.08 (1.67–2.60)                | <0.001  | 1.54 (1.22–1.95)                  | <0.001  |
|                                       | No                    | 3.51 (1.72–7.16)                | <0.001  | 2.89 (1.40–5.96)                  | 0.004   |
| Diabetes, n (%)                       | Yes                   | 1.93 (1.49–2.49)                | <0.001  | 1.34 (1.02–1.75)                  | 0.032   |
|                                       | No                    | 2.11 (1.45–3.07)                | <0.001  |                                   |         |
| Previous stroke, n (%)                | Yes                   | 2.17 (1.67–2.80)                | <0.001  | 1.63 (1.25–2.13)                  | <0.001  |
|                                       | No                    | 1.35 (1.05–1.73)                | 0.019   |                                   |         |
| Previous transient ischaemic attack, n (%) | Yes  | 95 (1.5)  | 1.35 (1.08–1.70) | 0.001 |  | |
|                                       | No                    | 346 (1.1)  | 1.49 (1.10–2.01) | 0.009 |  | |
| Prior myocardial infarction, n (%)    | Yes                   | 49 (1.7)  | 3.65 (2.53–5.27) | <0.001 | 2.55 (1.73–3.76) | <0.001 |
|                                       | No                    | 392 (1.2)  | 2.04 (1.60–2.62) | <0.001 | 1.67 (1.28–2.17) | <0.001 |
| Heart failure, n (%)                  | Yes                   | 371 (1.1)  | 2.70 (2.37–3.07) | <0.001 |  | |
|                                       | No                    | 371 (1.1)  | 1.35 (1.05–1.73) | 0.019 |  | |
| Chronic respiratory disease, n (%)    | Yes                   | 366 (1.1)  | 1.35 (1.08–1.70) | 0.001 |  | |
|                                       | No                    | 346 (1.1)  | 1.49 (1.10–2.01) | 0.009 |  | |
| Renal failure, n (%)                  | Yes                   | 30 (2.4)  | 3.65 (2.53–5.27) | <0.001 | 2.55 (1.73–3.76) | <0.001 |
|                                       | No                    | 369 (1.1)  | 2.04 (1.60–2.62) | <0.001 | 1.67 (1.28–2.17) | <0.001 |
| Peripheral vascular disease, n (%)    | Yes                   | 411 (1.2)  | 2.17 (1.67–2.80) | <0.001 | 1.63 (1.25–2.13) | <0.001 |
|                                       | No                    | 371 (1.1)  | 1.35 (1.05–1.73) | 0.019 |  | |
| History of cancer, n (%)              | Yes                   | 271 (1.1)  | 2.17 (1.67–2.80) | <0.001 | 1.63 (1.25–2.13) | <0.001 |
|                                       | No                    | 371 (1.1)  | 1.35 (1.05–1.73) | 0.019 |  | |
| Prior hospitalization for bleeding, n (%) | Yes | 95 (1.5)  | 3.65 (2.53–5.27) | <0.001 | 2.55 (1.73–3.76) | <0.001 |
|                                       | No                    | 346 (1.1)  | 2.04 (1.60–2.62) | <0.001 | 1.67 (1.28–2.17) | <0.001 |
| Angina at rest, requiring intravenous nitrates, n (%) | Yes | 78 (2.2)  | 2.04 (1.60–2.62) | <0.001 | 1.67 (1.28–2.17) | <0.001 |
|                                       | No                    | 360 (1.1)  | 1.76 (1.39–2.23) | <0.001 |  | |

CI: confidence interval; OR: odds ratio; SD: standard deviation.

### Table 3: The crude mortality and adjusted mortality risk in coronary artery bypass grafting patients with and without perioperative stroke

|                     | Stroke patients, % (n) | No-stroke patients, % (n) | Hazard ratio (95% CI) | P-Value |
|---------------------|------------------------|---------------------------|-----------------------|---------|
| Mortality overall   | 50.8 (224/441)         | 19.5 (6990/36 457)        | 2.30 (2.00–2.64)      | <0.0001 |
| Mortality within 30 days | 16.3 (72/441)         | 1.3 (455/36 457)         | 7.29 (5.58–9.54)      | <0.0001 |
| Mortality from 30 days to 1 year | 12.6 (40/329)        | 1.8 (639/35 401)         | 3.67 (2.61–5.15)      | <0.0001 |
| Mortality from 1 to 5 years | 13.1 (38/291)         | 7.7 (2530/32 871)        | 1.10 (0.79–1.52)      | 0.57    |
| Mortality from 5 years | 34.1 (74/224)          | 11.4 (3366/29 505)       | 1.76 (1.39–2.23)      | <0.0001 |

The models have been adjusted for sex, age, history of myocardial infarction, previous stroke, previous transient ischemic attack, diabetes, hypertension, heart failure, atrial fibrillation, renal failure, peripheral vascular disease, history of cancer, hospitalization for bleeding, chronic respiratory disease, acute coronary syndrome, mechanical circulatory assist preoperatively, prior cardiac surgery, critical preoperative state and angina at rest.

CI: confidence interval.
871) in the no-stroke group (P < 0.001), Table 3. After multi-adjustment, the HR for mortality in stroke patients was during this period 1.10 (95% CI 0.79–1.52) (P = 0.57). For the period after 5 years, the unadjusted mortality was 34.1% (74/224) vs 11.4% (3 366/29 505) and the aHR 1.76 (95% CI 1.39–2.23) (P < 0.001), Table 3.

DISCUSSION

The main findings in this nationwide observational cohort study were that the incidence of perioperative stroke after CABG remained largely unchanged over time and that patients with perioperative stroke had a markedly higher adjusted risk of death early after surgery. The increased mortality risk was sustained up to 12 years after the index operation.

The incidence of stroke after CABG in our large study cohort was 1.2%, which is comparable or lower than in most previous studies on the subject. In Gaudino et al.’s [5] recent large meta-analysis in mixed cardiac surgery patients, the incidence of perioperative stroke was 2.0%. In a systematic review of CABG patients, the incidence varied between 1.1% and 5.7% in the included studies [6] while a very large registry study from the USA, compromising over 668 000 CABG patients reported an incidence of 1.9% [1].

The unadjusted incidence of perioperative stroke in our study remained largely unchanged during the period 2006–2017. In contrast to most previous reports, we also analysed the adjusted incidence over time and found that, when adjusted for factors associated with stroke risk, there was a statistically significant reduction in the perioperative stroke risk over time. However, this information should not be overvalued since the reduction was small (relative reduction ~3% per year). This is a very marginal reduction given the 1.2% absolute annual incidence and hence not clinically meaningful.

In the present study, we also identified preoperative risk factors associated with perioperative stroke. The majority of these have been previously identified and were thus confirmed in the present large cohort study. It can be noted that the importance of the patient’s preoperative condition was strong, as also age, previous stroke and the presence of peripheral arterial disease. Female sex was also identified as a strong independent factor, which is in accordance with previous studies [2, 15]. There was a significant interaction with age for female sex with relatively higher risk for women <70 years old, but no interaction with previous stroke, previous heart surgery or preoperative critical state.

Thirty-day mortality was 13-fold higher (16.3% vs 1.3%) in patients with perioperative stroke. This confirms the extremely high mortality in perioperative stroke previously reported [4, 15–17]. Similar figures were reported in Gaudino et al.’s [5] study in mixed cardiac surgery patients where there was a 12-fold difference. After adjustment in the present study for the increased prevalence of risk factors in patients that developed stroke, the OR for mortality in CABG patients with perioperative stroke remained markedly increased (adjusted OR 7.3). This points to the importance of addressing this potential complication in CABG patients and that even a small reduction in the incidence of perioperative stroke would save lives. Perioperative stroke was also associated with increased long-term mortality risk, also when patients who died early were excluded. The adjusted long-term mortality risk after CABG has not been as thoroughly investigated previously as the early risk but there are some reports with similar findings [5, 18–20]. The increased long-term risk indicates that long-term surveillance and secondary prevention measures are of utmost importance in patients who develop perioperative stroke.
Limitations and strengths

This study has both strengths and limitations. The main limitation of this study is the retrospective nature of the study. While the data are collected prospectively, eliminating recall bias, there is always the risk of selection bias, as well as residual confounding. Another limitation of the study is the inability of our dataset to further define the severity of the stroke and its impact on the patients. Information about the proportion of stroke patients who underwent imaging is lacking in the registries. It should also be noted that we did not investigate the association between intraoperative factors and perioperative stroke. Factors such as cardiopulmonary bypass time and type of surgery have previously been shown to be associated with the risk for perioperative stroke in cardiac surgery patients [3, 4, 16]. One may argue that we should have included also perioperative factors in our statistical models but it adds methodological complexity to mix preoperative factors, known at the time of the decision to operate, with intraoperative factors, unknown at the time of the decision. One of the prespecified aims of the present study was to identify preoperative factors associated with perioperative stroke. This aim was included to gain information that could support the heart team in the discussions on the risk for perioperative stroke. Including also perioperative factors may blur the picture.

The strengths include the large study population in a real-world setting, the long and extensive follow-up, the nationwide coverage with a high degree of data completeness in validated mandatory national registries and databases and a primary end point (all-cause mortality) not subject to bias.

CONCLUSIONS

There was a marginal decrease in the incidence of perioperative stroke over the study period. Patients with perioperative stroke have a markedly higher adjusted mortality risk of death early after surgery. The risk declines over time but remains higher during the entire follow-up period. Efforts to reduce the incidence of perioperative stroke are essential.

SUPPLEMENTARY MATERIAL

Supplementary material is available at EJCTS online.

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Author contributions

Kristian Jonsson: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing—original draft; Writing—review & editing. Mikael Barbu: Conceptualization; Formal analysis; Writing—review & editing. Susanne J. Nielsen: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Writing—original draft; Writing—review & editing. Brynhildur Hafsteinsdottir: Formal analysis; Methodology; Writing—review & editing. Tomáš Gudbjartsson: Conceptualization; Writing—review & editing. Elin M. Persson: Conceptualization; Writing—review & editing. Martin Silverborn: Conceptualization; Formal analysis; Writing—review & editing. Anders Jeppsson: Conceptualization; Data curation; Formal analysis; Methodology; Project administration; Supervision; Writing—original draft; Writing—review & editing.

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REFERENCES

[1] Shahian DM, OBrien SM, Fidario G, Ferraris VA, Haan CK, Rich JB et al. The Society of Thoracic Surgeons 2008 cardiac surgery risk models: part 1—coronary artery bypass grafting surgery. Ann Thorac Surg 2009;88: S2–S22.
[2] Anyanwu AC, Filsoofi F, Salzberg SP, Bronster D, Adams DH. Epidemiology of stroke after cardiac surgery in the current era. J Thorac Cardiovasc Surg 2007;134:1121–7.
[3] Bucenus J, Gunnert JF, Borger MA, Walther T, Doll N, Onnassch JF et al. Stroke after cardiac surgery: a risk factor analysis of 16,184 consecutive adult patients. Ann Thorac Surg 2003;75:472–8.
[4] Karunananthan J, Ali JM, Evans NR, Webb S, Large SR. Impact of stroke on outcomes following cardiac surgery: propensity matched analysis. J Card Surg 2020;35:3010–6.
[5] Gaudino M, Rahouma M, Di Mauro M, Yanagawa B, Abouarab A, Demetres M et al. Early versus delayed stroke after cardiac surgery: a systematic review and meta-analysis. J Am Heart Assoc 2019;8: e012447.
[6] Mao Z, Zhong X, Yin J, Zhao Z, Hu X, Hackett ML. Predictors associated with stroke after coronary artery bypass grafting: a systematic review. J Neurol Sci 2015;357:1–7.
[7] Mehta A, Gleason T, Wechsler L, Winger D, Wang L, Thirumala PD. Perioperative stroke as a predictor of mortality and morbidity in patients undergoing CABG. J Clin Neurosci 2017;44:175–9.
[8] Santos HN, Magedanz EH, Guarragna JC, Santos NN, Albuquerque LC, Goldani MA et al. Predictors of stroke in patients undergoing cardiac surgery. Rev Bras Cir Cardiovasc 2014;29:140–7.
[9] LaPar DJ, Quader M, Rich JB, Kron IL, Crosby IK, Kern JA et al. Institutional variation in mortality after stroke after cardiac surgery: an opportunity for improvement. Ann Thorac Surg 2015;100: 1276–82.
[10] von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP; STROBE Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Int J Surg 2014;12:1495–9.
[11] Jernberg T, Attebring MF, Hambraeus K, Ivert T, James S, Jeppsson A et al. The Swedish Web-system for Enhancement and Development of Evidence-based care in Heart disease Evaluated According to Recommended Therapies (SWEDHEART). Heart 2010;96:1617–21.
[12] Nashef SAM, Roques F, Michel P, Gauducheau E, Lemeshow S, Salamon R. European System for Cardiac Operative Risk Evaluation (EuroSCORE). Eur J Cardiothorac Surg 1999;16:9–13.
[13] Ludvigsson JF, Andersson E, Ekborn A, Feychting M, Kim J-L, Reuterwall C et al. External review and validation of the Swedish national inpatient register. BMC Public Health 2011;11:450.
[14] Brooke HL, Talback M, Hornblad J, Johansson LA, Ludvigsson JF, Druid H et al. The Swedish cause of death register. Eur J Epidemiol 2017;32:765–73.

[15] Sultan I, Bianco V, Kilic A, Jovin T, Jadhav A, Jankowitz B et al. Predictors and outcomes of ischemic stroke after cardiac surgery. Ann Thorac Surg 2020;110:448–56.

[16] Raffa GM, Agnello F, Occhipinti G, Miraglia R, Lo Re V, Marrone G et al. Neurological complications after cardiac surgery: a retrospective case-control study of risk factors and outcome. J Cardiothorac Surg 2019;14:23.

[17] Salazar JD, Wityk RJ, Grega MA, Borowicz LM, Doty JR, Petrofski JA et al. Stroke after cardiac surgery: short- and long-term outcomes. Ann Thorac Surg 2001;72:1195–201.

[18] Tarakji KG, Sabik JF, 3rd, Bhudia SK, Batsy LH, Blackstone EH. Temporal onset, risk factors, and outcomes associated with stroke after coronary artery bypass grafting. J Am Med Assoc 2011;305:381–90.

[19] Hedberg M, Boivie P, Engstrom KG. Early and delayed stroke after coronary surgery—an analysis of risk factors and the impact on short- and long-term survival. Eur J Cardiothorac Surg 2011;40:379–87.

[20] Filsoufi F, Rahmanian PB, Castillo JG, Bronster D, Adams DH. Incidence, topography, predictors and long-term survival after stroke in patients undergoing coronary artery bypass grafting. Ann Thorac Surg 2008;85:862–70.