Chula Med J Vol. 66 No. 3 July - September 2022;319-328 DOI : 10.14456/clmj.2022.39

Original article

# Incidence and imaging pattern of stroke after cardiac surgery

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***Background:*** Few cases of patients of previous studies have provided information on imaging patterns of stroke after cardiac surgery.
***Objective:*** The purpose of this study was to determine the incidence and imaging pattern of stroke after cardiac surgery according to type of cardiac surgery.
***Methods:*** A retrospective observational study was conducted on 3,645 adult patients who underwent cardiac surgery in cardiovascular thoracic unit at our institute from January 1, 2010 – September 30, 2019. Cases of patients who were suspected of having post-operative stroke and on whom brain imaging had been performed were reviewed. The ischemic stroke was categorized into four subtypes including large territorial infarction, multiple scattered infarctions, small infarction, and watershed infarction.
***Results:*** Stroke after cardiac surgery was suspected in 90 patients. Sixty-seven patients (1.8%) had a diagnosis of ischemic stroke confirmed by imaging. The incidence of stroke in combined cardiac procedure with carotid bypass surgery was significantly high, especially in thoracic endovascular aortic repair (TEVAR) with carotid bypass surgery ($P < 0.001$). Multiple scattered infarctions (61.2%) was the most common pattern which was predominant in both anterior and posterior circulation. It was found to have no significant association between type of surgery and pattern of stroke ($P = 0.70$). Overall, stroke related death within 30 days post cardiac surgery was 0.2% (7/3645).
***Conclusions:*** Procedures that included carotid bypass surgery increased the incidence of stroke after cardiac surgery significantly, especially TEVAR with carotid bypass surgery. The most common pattern of stroke after cardiac surgery was the multiple scattered pattern.

***Keywords:*** Cardiac surgery, post-operative stroke, stroke.

Stroke is one of the devastating post-operative complications of cardiac surgery. The incidence of stroke after cardiac surgery has been reported to vary between 0.8% and 5.2%, depending on the procedure.(1) Although stroke after cardiac surgery can be categorized as either ischemic or hemorrhagic stroke, the more common finding is ischemic stroke.(2) Two main mechanisms of ischemic stroke after cardiac surgery were proposed including: 1) embolic due to atrial fibrillation, carotid atherosclerotic emboli, air emboli; and, 2) cerebral hypoperfusion, which is mainly due to hemodynamic instability.(3) The infarction pattern and distribution of ischemic stroke may depend on the sources of emboli and its mechanism.(4) However, risk factors such as cardiac and arterial disease frequently coexist, the determination for a single cause of stroke becomes difficult. The pattern of embolic infarctions can appear as multiple scattered infarct lesions as well as a single large territorial infarction.(5)

In the past decade, many elderly patients who have had multiple co-morbid diseases underwent cardiac surgery. Thus, the risk of developing stroke after cardiac surgery has increased.(6) However, few cases of patients of previous studies have provided information on imaging patterns of stroke after cardiac surgery according to each type of cardiac surgery.

The purpose of this study was to determine the incidence of stroke after cardiac surgery according to the type of cardiac surgery, and identify the imaging pattern of stroke after cardiac surgery according to the type of cardiac surgery.

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Received: October 13, 2021
Revised: November 30, 2021
Accepted: December 9, 2021

## Materials and methods

### *Patient selection*

The study protocol was approved by the Research Ethics Committee of our institute. We collected the data from 3,645 adult patients (18 years old and above) who had undergone cardiac surgery from January 1, 2010 – September 30, 2019 in the cardiovascular thoracic unit at our institute. Cardiac surgery included coronary artery bypass grafting (CABG), valvular heart surgery, CABG with valvular heart surgery, aortic procedure (ascending aorta and aortic arch), carotid endarterectomy, carotid bypass surgery and combined cardiac procedure. Patients who underwent any other major concomitant non-cardiac surgery procedure with underlying vasculitis such as Takayasu arteritis were excluded. Patient characteristics and procedures are shown in Table 1.

The target population was adult patients with a diagnosis of a cerebrovascular accident within 14 days after cardiac surgery. Stroke was defined as a focal neurological deficit adjudicated by a neurologist and confirmed via computed tomography (CT) or magnetic resonance imaging (MRI).(7) The onset of stroke was defined as either occurring within 24 hours postoperatively (immediately stroke) or after 24 hours postoperatively but within 14 days (delayed stroke). The mean of the onset of stroke after operation in this study was 2.9 days. Most of the patients underwent initial brain imaging after 24 hours postoperatively [52 patients (77.6%)].

CT examination was performed on five different CT scanners (Toshiba; Aquilion one, GE; Discovery, GE; Revolution, Philips; Ingenuity, and Siemens; Somatom Force) in helical mode. All scans were performed by using automatic tube current modulation and set the tube voltage at 120 KV. These examinations were performed variable slice thickness ranging from 4 to 5 mm and 5 mm spacing. The default brain image was present to a 90 Hounsfield (HU) *window* width and 40 HU window length. The stroke review settings were set to 40 HU window width and 40 HU window length.

MRI studies were performed using 1.5 tesla MRI scanners (Siemens; Aera, Philips; Ingenia) or 3.0-tesla scanners (Seimens; Skyra, Philips; Ingenia, GE healthcare; Discovery 750w). All MRI studies included Diffusion weighted imaging (DWI) (b-value 0, 1,000), Apparent diffusion coefficient (ADC) and eADC map, with 5 mm thickness and 5 - 6 mm spacing. Other sequences in stroke protocol including axial T1 weighted image (T1WI), axial T2WI, axial T2/Fluid attenuated inversion recovery (FLAIR), axial susceptibility weighted imaging (SWI) and coronal gradient echo T2WI were performed.

Among the 3,645 adult patients, 90 were suspected of having a post-operative stroke by a neurologist examining medical records which included brain imaging. Initially, 23 patients were excluded because their imaging showed no evidence of acute ischemic stroke: chronic infarction (n = 13), intracranial hemorrhage (n = 3), tumor (n = 1), or negative study (n = 6). Consequently, post-operative acute ischemic stroke was observed in 67 patients.

### *Data collection*

The imaging study was evaluated by a radiologist (ND) with 10 years of experience. We categorized the pattern of ischemic stroke into four groups including large territorial infarction, multiple scattered infarctions, small infarction, and watershed infarction following Kim YD, *et al.* (4), as shown in Figure 1. The large territorial infarction was defined as a single lesion of a size ≥ 15 mm in any arterial territory. Multiple scattered infarctions was defined as having more than one lesion even if located in the same vascular territory. The small infarction was displayed as a single lesion of a size < 15 mm in any arterial territory. The watershed infarction was defined as an infarction at the junction between two main arterial territories.(4, 8)

For patients on whom angiography study was performed such as CT angiography (CTA) of the brain and neck or magnetic resonance angiography (MRA) of the brain and neck evaluation, we also assessed the angiography study including the intracranial cerebral arteries (middle cerebral artery (MCA), anterior cerebral artery (ACA), posterior cerebral artery (PCA), basilar artery, intracranial carotid artery, and intracranial vertebral artery) and extracranial cerebral arteries (extracranial carotid artery, extracranial vertebral artery, innominate artery, and subclavian artery). Each segment of the carotid and vertebrobasilar arterial systems was classified as normal, mild stenosis (< 50.0%), moderate stenosis (50.0 – 69.0%) or severe stenosis/occlusion (> 70.0%).(9)

Furthermore, we also evaluated the aortic arch pathologies from the CTA or MRA. These were categorized into aortic atherosclerosis, aortic aneurysm, aortic dissection, and intramural hematoma.

Clinical information and perioperative data were also included.

**Table 1.** Patient characteristics and incidence of stroke according to type of cardiac surgery.

| Patient characteristics | Overall (n = 3,645, 100.0%) | Stroke (n = 67, 100.0%) | Incidence (%) | *P* -value* |
|---|---|---|---|---|
| Age (mean ± SD) (years) | 63.6 ± 13.6 (18 - 101) | 67.0 ± 14.2 (28 - 89) | | |
| **Gender** | | | | |
| Female | 1,394 (38.2) | 25 (37.3) | | |
| Male | 2,251 (61.8) | 42 (62.7) | | |
| **Type of cardiac surgery** | | | | |
| CABG | 1,472 (40.3) | 22 (32.8) | 1.5 | 0.204 |
| Valvular heart surgery | 1,291 (35.4) | 18 (26.9) | 1.4 | 0.140 |
| **Aortic procedure** | 237 (6.5) | 4 (6.0) | 1.7 | 0.859 |
| Open repair surgery | 168 | 4 | | |
| TEVAR | 69 | 0 | | |
| **Carotid endarterectomy** | 35 (1.0) | 0 (0.0) | 0.0 | 0.416 |
| **Carotid bypass surgery** | 13 (0.4) | 1 (1.5) | 7.7 | 0.115 |
| **Combined cardiac surgery** | 597 (16.4) | 22 (32.8) | 3.7 | |
| CABG with valvular heart surgery | 305 (8.4) | 5 (7.5) | 1.6 | 0.787 |
| CABG with aortic procedure | 35 (1.0) | 2 (3.0) | 5.7 | 0.086 |
| CABG with carotid endarterectomy | 12 (0.3) | 1 (1.5) | 8.3 | 0.093 |
| CABG with carotid bypass surgery | 4 (0.1) | 0 (0.0) | 0.0 | 0.784 |
| Aortic procedure with valvular heart surgery | 111 (3.0) | 3 (4.5) | 2.7 | 0.491 |
| TEVAR with LSA coverage and carotid bypass surgery | 109 (3.0) | 9 (13.4) | 8.3 | < 0.001 |
| CABG with aortic and carotid bypass surgery | 5 (0.1) | 2 (3.0) | 40.0 | < 0.001 |
| CABG with valvular heart surgery and aortic procedure | 16 (0.4) | 0 (0.0) | 0.0 | 0.583 |

**P* - value corresponds to Chi-square test
CABG = Coronary artery bypass grafting, TEVAR = Thoracic endovascular aortic repair, LSA = Left subclavian artery

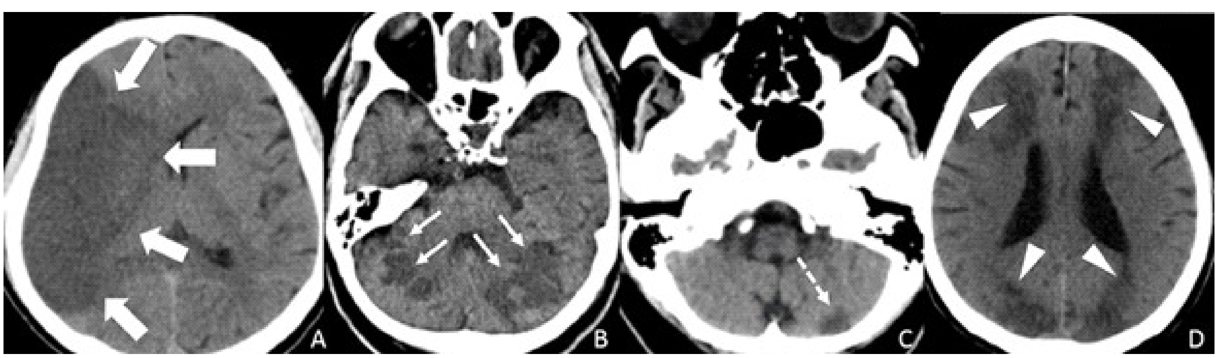


**Figure 1.** Stroke after cardiac surgery categorized into 4 patterns **(A)** a large territorial infarction (thick arrow), **(B)** multiple scattered infarctions (arrow), **(C)** a small infarction (dashed arrow) and **(D)** a watershed infarction (arrow head).

***Statistical analysis***

All statistical analysis was performed using SPSS 22.0 software. Continuous variables are presented as mean ± standard deviation (SD). Categorical variables are shown as count and percentage of the sample. Comparison of categorical variables was performed using chi square tests. Comparison of continuous variables was performed using unpaired *t* - tests. A *P* -value < 0.05 was considered statistically significant for all used tests.

## Results

### *Incidence of stroke*

Stroke after cardiac surgery was observed in 67 patients (incidence 1.8 %) as shown in Table 1. The incidence of stroke varied by procedure. The highest incidence of stroke was found in CABG patients with aortic procedure and carotid bypass surgery 40.0%, followed by thoracic endovascular aortic repair (TEVAR) with left subclavian artery coverage and carotid bypass surgery 8.3% and CABG with carotid endarterectomy 8.3%. Procedures that included carotid bypass surgery were found to increase the rate of stroke except four patients who underwent CABG with carotid bypass surgery.

In terms of demographics, no significant difference was found regarding comorbidities and operative data between groups who underwent cardiac surgery without carotid bypass surgery and combined cardiac surgery with carotid bypass surgery, as shown in Table 2.

**Table 2.** Comparison of demographic data and perioperative risk factor between groups undergoing cardiac surgery without carotid bypass surgery and cardiac surgery with carotid bypass surgery.

| General data | Total patients with ischemic stroke (n = 67) (%) | Cardiac surgery without carotid bypass surgery (n = 55) (%) | Cardiac surgery with carotid bypass surgery (n = 12) (%) | *$P$ - value |
|---|---|---|---|---|
| **Age (years)** | 67.1 ± 14.1 | 66.5 ± 13.7 | 69.8 ± 16.2 | 0.470 |
| **Gender (male)** | 42 (62.7) | 36 (65.5) | 7 (58.3) | 0.501 |
| **Body mass index (kg/m$^2$)** | 22.6 ± 8.0 | 22.0 ± 7.4 | 25.2 ± 10.6 | 0.218 |
| **Underlying disease** | | | | |
| Hypertension | 50 (74.6) | 39 (70.9) | 11 (91.7) | 0.258 |
| Hyperlipidemia | 37 (55.2) | 28 (50.9) | 8 (75.0) | 0.230 |
| Diabetes mellitus | 17 (25.8) | 17 (30.9) | 0 (0.0) | 0.062 |
| Coronary artery disease | 26 (38.8) | 22 (40.0) | 4 (33.3) | 0.918 |
| Preoperative atrial fibrillation | 13 (19.4) | 13 (23.6) | 0 (0.0) | 0.141 |
| History of cerebrovascular accident | 13 (19.4) | 11 (20.0) | 1 (8.3) | 1.000 |
| Prior cardiac operation | 7 (10.4) | 5 (9.1) | 2 (16.7) | 0.798 |
| History of smoking | 20 (29.9) | 17 (30.9) | 3 (25.0) | 0.954 |
| Use of oral anticoagulant | 10 (14.9) | 10 (18.2) | 0 (0.0) | 0.248 |
| Use of antiplatelets | 34 (52.2) | 28 (50.9) | 7 (58.3) | 0.883 |
| **CCardiac data** | | | | |
| LVEF % | 56.9 ± 14.4 | 56.7 ± 14.8 | 58.4 ± 12.4 | 0.732 |
| **NYHA** | | | | |
| I | 21 (31.3) | 16 (29.1) | 5 (41.7) | 0.598 |
| II | 33 (49.3) | 29 (52.7) | 4 (33.3) | |
| III | 12 (17.9) | 9 (16.4) | 3 (25.0) | |
| IV | 1 (1.5) | 1 (1.8) | 0 (0.0) | |
| **Operation data** | | | | |
| Cardiopulmonary bypass time (minutes) | 146.4 ± 69.4 | 147.8 ± 71.2 | 130.8 ± 50.6 | 0.644 |
| Aortic cross-clamp time (minutes) | 96.0 ± 43.6 | 97.3 ± 45.0 | 81.5 ± 19.4 | 0.493 |
| Lowest core temperature (°C) | 29.5 ± 5.4 | 29.7 ± 5.5 | 27.6 ± 4.1 | 0.451 |
| **Postoperative data** | | | | |
| Severe hypotension | 13 (19.4) | 10 (18.2) | 3 (25.0) | 0.890 |
| Atrial fibrillation | 25 (37.3) | 22 (40.0) | 3 (25.0) | 0.330 |

* $P$ - value corresponds to independent $t$ - test and Chi-square test

LVEF = left ventricular ejection fraction, NYHA = New York Heart Association functional classification

***Imaging pattern of stroke after cardiac surgery according to the type of cardiac surgery***

Of the 67 patients with ischemic stroke, the first brain imaging studies revealed evidence of acute infarction in 57 cases (85.1%), with ten patients not showing any evidence of acute ischemic stroke in the first CT brain imaging, including a patient with acute subdural hematoma who had undergone follow-up brain imaging which showed evidence of acute infarction (MRI in 7 patients and CT in 3 patients), as shown in Figure 2.

Angiographic imaging of the brain study was performed for 38 patients (56.7%) (CTA for 25 patients (37.3%) and MRA on 13 patients (19.4%)), while angiographic imaging of the neck was reviewed for 47 patients (70.1%) (CTA for 35 patients and MRAon 12 patients).

Of those 67 patients who demonstrated acute infarction in the brain imaging, most patients presented with multiple scattered infarctions (41 patients or 61.2%). Other patterns were shown as a single large territorial infarction in 19 patients (28.4%), a single small infarction in 5 patients (7.5%) and watershed infarction for 2 patients (3.0%). Table 3 shows the pattern of stroke after cardiac surgery according to type of cardiac surgery. No statistically significant association found between type of cardiac surgery and pattern of stroke (*P* = 0.699).

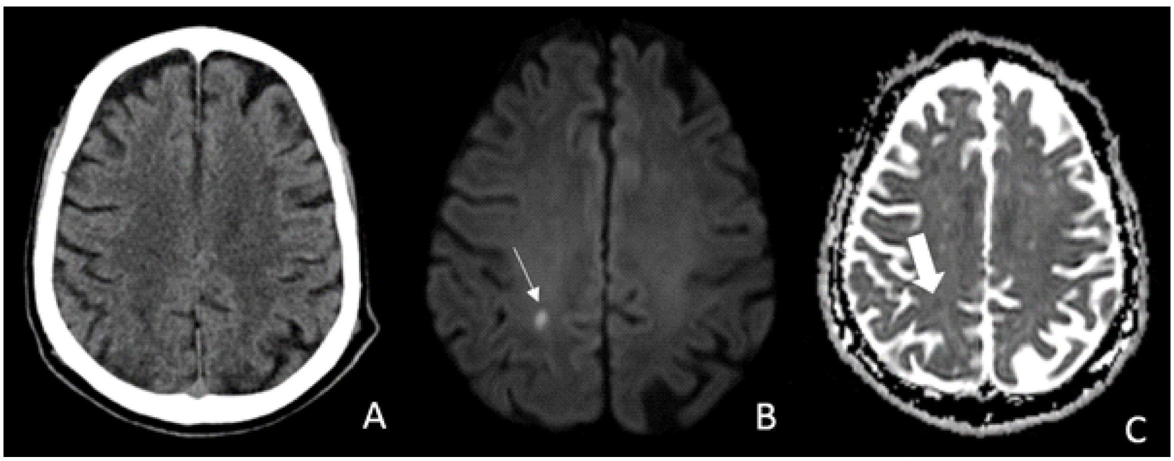


**Figure 2.** (**A**) Initial CT of the brain is negative. **(B, C)** Follow up MRI at day 17th shows hyperintensity on DWI (arrow) and hypointensity on ADC (thick arrow), corresponding with acute-early subacute infarction.

**Table 3.** Pattern of stroke after cardiac surgery according to type of cardiac surgery.

| Type of cardiac surgery | Total n | Large territorial infarction n (%) | Multiple scattered infarction n (%) | Small infarction n (%) | Watershed infarction n (%) | **P*-value |
|---|---|---|---|---|---|---|
| CABG | 22 | 6 (27.3) | 14 (63.6) | 2 (9.1) | 0 (0.0) | |
| Valvular heart | 18 | 7 (38.9) | 8 (44.4) | 3 (16.7) | 0 (0.0) | |
| Aortic procedure | 4 | 1 (25.0) | 3 (75.0) | 0 (0.0) | 0 (0.0) | |
| Carotid bypass surgery | 1 | 1 (100.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | |
| Combined cardiac surgery | 22 | 4 (18.2) | 16 (72.7) | 0 (0.0) | 2 (9.1) | 0.699 |
| • CABG with valvular heart surgery | 5 | 1 (20.0) | 3 (60.0) | 0 (0.0) | 1 (20.0) | |
| • CABG with aortic procedure | 2 | 0 (0.0) | 2 (100.0) | 0 (0.0) | 0 (0.0) | |
| • CABG with carotid endarterectomy | 1 | 1 (100.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | |
| • Aortic procedure with valvular heart surgery | 3 | 1 (33.3) | 2 (66.7) | 0 (0.0) | 0 (0.0) | |
| • Aortic procedure with carotid bypass surgery | 9 | 1 (11.1) | 7 (77.8) | 0 (0.0) | 1 (11.1) | |
| • CABG with aortic and carotid bypass surgery | 2 | 0 (0.0) | 2 (100.0) | 0 (0.0) | 0 (0.0) | |
| Total | 67 | 19 (28.3) | 41 (61.2) | 5 (7.5) | 2 (3.0) | |

* *P* - value corresponds to Chi-square test
CABG = Coronary artery bypass grafting

As for the large territorial infraction, the majority occurred in the MCA territory (n = 16, 84.2%), more on the right (n = 10). There were two patients in whom the infarction involved the internal carotid artery territory (n = 2, 10.5%); one on the right and another on the left. A basilar artery territory infarction was observed in one patient (n = 1, 5.3%). Three patients (15.7%) underwent mechanical thrombectomy, representing 4.5% of all patients with postoperative stroke.

Most of the embolic strokes occurred in both anterior and posterior circulation (29/41, 70.7%), isolated anterior circulation (6/41, 14.6%), and isolated posterior circulation (6/41, 14.6%).

***Risk factors***

Of the 67 patients, there was angiography imaging that included aortic arch in 45 patients (67.2%). In the aortic arch aneurysm, cerebral infarction solely occurred in the multiple scattered pattern ($P = 0.046$) as shown in Figure 3, whereas the degree of intracranial or extracranial atherosclerosis was not significantly associated with pattern of ischemic stroke as shown in Table 4.

***Progression of stroke***

Follow-up brain imaging was performed on 46 patients (68.7%) and demonstrated progression of stroke in 15 patients (32.6%) as shown in Table 5. Most of the infarct progression showed an increase in extension and pressure effect of the infract area, and some developed hemorrhagic transformation. Decompressive craniotomies were performed on two patients with a large territorial infarction.

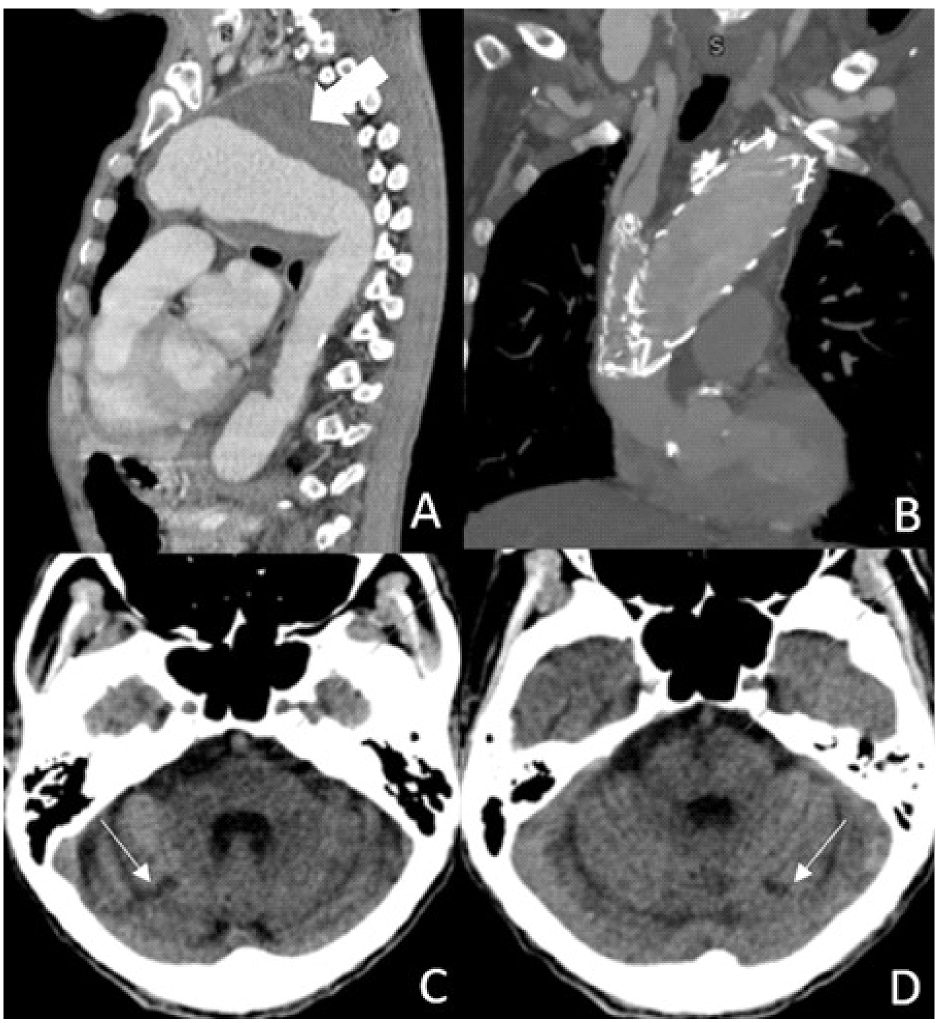


**Figure 3.** Aortic arch aneurysm in a patient on whom TEVAR with carotid bypass surgery was performed. **(A)** Sagittal oblique CTA of the thoracic aorta shows distal aortic arch aneurysm with circumferential soft plaque (arrow). **(B)** Post-operative coronal CTA of the thoracic aorta shows evidence of endovascular stent placed from ascending aorta covering left subclavian artery with chimney stent placed in brachiocephalic artery. **(C, D)** Axial unenhanced CT image (post operation) shows few small, scattered infarctions in bilateral cerebellar hemispheres (arrow).

**Table 4.** Pattern of stroke after cardiac surgery according to the aortic arch pathology and angiography study.

| Risk factor | Total n | Large territorial infarction n (%) | Multiple scattered infarction n (%) | Small arterial infarction n (%) | Watershed n (%) | *P - value |
|---|---|---|---|---|---|---|
| **Aortic arch pathology** | | | | | | |
| Normal | 14 | 6 (42.9) | 6 (42.9) | 2 (14.2) | 0 (0.0) | 0.200 |
| Aortic atherosclerosis | 12 | 3 (25.0) | 7 (58.4) | 1 (8.3) | 1 (8.3) | 0.621 |
| Aortic aneurysm | 14 | 0 (0.0) | 14 (100.0) | 0 (0.0) | 0 (0.0) | 0.046 |
| Aortic dissection | 3 | 2 (66.7) | 1 (33.3) | 0 (0.0) | 0 (0.0) | 0.490 |
| Intramural hematoma | 2 | 1 (50.0) | 1 (50.0) | 0 (0.0) | 0 (0.0) | 0.892 |
| **Angiography of brain and neck** | | | | | | |
| **Intracranial atherosclerosis** | | | | | | |
| Normal to mild stenosis | 12 | 1 (9.1) | 9 (40.9) | 2 (40.0) | 0 (0.0) | 0.224 |
| Moderate to severe stenosis | 26 | 10 (90.9) | 13 (59.1) | 3 (60.0) | 0 (0.0) | 0.067 |
| **Extracranial atherosclerosis** | | | | | | |
| Normal to mild stenosis | 24 | 6 (54.5) | 14 (46.7) | 4 (80.0) | 0 (0) | 0.079 |
| Moderate to severe stenosis | 23 | 5 (45.5) | 16 (53.3) | 1 (20.0) | 1 (100.0) | 0.879 |

* *P* - value corresponds to Chi-square test

**Table 5.** Progression of stroke after cardiac surgery according to pattern of ischemic infarction.

| Pattern of ischemic infarction | Total n | No progression n (%) | Progression of stroke n (%) | *P-value |
|---|---|---|---|---|
| Large territorial infarction | 15 | 8 (53.3) | 7 (46.7) | 0.157 |
| Multiple scattered infarction | 26 | 18 (69.2) | 8 (30.8) | 0.762 |
| Small arterial infarction | 4 | 4 (100.0) | 0 (0.0) | 0.145 |
| Watershed | 1 | 1 (100.0) | 0 (0.0) | 0.482 |
| Total | 46 | 31 (67.4) | 15 (32.6) | |

* *P* - value corresponds to Chi-square test

### *Survival*

Survival data were incomplete; they included only 61 patients. The average length of stay in the hospital was 27.9 days**.** The mortality rate within 30 days of hospitalization was 16.4% (10/61) with stroke related death in 7 patients (70.0%). Overall stroke related death within 30 days post cardiac surgery was 0.2% (7/3645).

## Discussion

The overall incidence of stroke after cardiac surgery in this study was 1.8%. The incidence varied according to the type of cardiac surgery. Previous studies have reported varied incidence of stroke after cardiac surgery between 0.8% and 5.2%.[1] The incidence of stroke in our study of 1.8% might be slightly underestimated. Twenty-three patients with clinically suspected stroke had no evidence of acute ischemic stroke from the initial CT scan of the brain; none of them received follow-up brain imaging. If we consider these 23 patients as false negative studies, the incidence of stroke after cardiac surgery in our study would be about 2.5%.

Compared with the overall incidence of stroke in isolated cardiac procedure (1.5% (45/3048), the combined cardiac procedure has a significantly higher incidence of postoperative stroke (3.7% (22/597)) except the incidence of stroke in combined CABG with valvular surgery (1.6%). This is not consistent with the previous study by Anyanwu AC, *et al*. in 2007 that reported higher incidence of stroke in combined CABG with valvular heart surgery (4.4%).[10] This may be due to advances in cardiothoracic surgery, anesthesiology as well as intensive care units in the past decades.

Interestingly, the incidence of stroke significantly increased with the combined procedure that included carotid bypass surgery such as aortic procedure with carotid bypass surgery (8.3%), in which all the patients underwent TEVAR with left subclavian artery coverage and carotid bypass surgery (left subclavian artery revascularization), while none of our patients who underwent TEVAR without carotid bypass surgery (69 patients) experienced stroke. The patient's demographics, comorbidities, and operative data between groups of cardiac surgery with and without carotid bypass surgery were similar. Thus we believe that left subclavian artery coverage with carotid bypass procedure itself is a risk factor. Consequently, the risks and benefits of left subclavian artery revascularization should be considered. Our results are supported by the previous study of Delafontaine JL, *et al*. that demonstrated significant increased rate of stroke in TEVAR with left subclavian artery revascularization as compared with TEVAR without left subclavian artery revascularization.(11)

A study conducted by Khattar NK, *et al*. reported the incidence of perioperative stroke of carotid endarterectomy as 3.6%, the possible mechanism being the manipulation of the intraluminal plaque.(12) There was no evidence of any post-operative stroke after isolated carotid endarterectomy in our cardiovascular thoracic unit. However, in our institute, some of the carotid endarterectomy procedures was performed in the neurosurgery unit their data were not included in our study.

Our study showed no significant association between type of surgical operation and pattern of stroke. These data supported the idea that the pattern of stroke after cardiac surgery may be multifactorial. The previous data indicated that the distribution pattern of embolic stroke may give a clue about the source of emboli. In the anterior cerebral circulation, emboli may be from atherosclerotic plaques of the carotid bifurcation, while in the posterior circulation, emboli may be from plaques in the subclavian or vertebral arteries. In addition, ruptured atheroma from the aortic arch may cause ischemic stroke in multiple vascular territories.(5) We found that intracranial or extracranial atherosclerosis was not significantly associated with pattern of ischemic stroke. This indicates that the source of emboli was from cardiac or atheroma aorta rather than from the intracranial and extracranial arteries.

The multiple scattered infarction pattern which involves both anterior and posterior circulation was the major pattern of the stroke occurring after cardiac surgery in our study. This pattern correlated with the typical pattern of cardioembolic infarction.(4) The previous study of Pierik R, *et al*. also proposed that multiple infarctions involving posterior cerebral circulation in patients with perioperative stroke were associated with a cardiac origin.(5)

The pattern of large territorial artery infarction was the second most common pattern of stroke after cardiac surgery (28.4%). The most common site of large territorial artery infarction was in the anterior circulation, MCA territory (84.2%). This also corresponds with a previous study which found that occlusion of MCA is the most common type in anterior circulation.(5, 13) Recent data published by Faheem S, *et al*. in July 2019 also found that the type of the cardiac procedure was not the predicting factor for large vessel occlusion, but that the prolonged aortic cross clamp and cardiac bypass times are the important risk factor for large vessel occlusion after cardiothoracic surgery.(13)

Another previous study found that impaired cerebral blood flow from cardiac surgery together with stenosis of the small penetrating arteries in the brain stem or subcortical lesions lead to small vessel occlusion.(14) In our study, some small infarctions involved the corticosubcortical regions. This might be associated with a very small embolic stroke rather than stenosis of a small penetrating artery. Our study supports that an MRI has greater sensitivity in detection early ischemic stroke and emphasizes the advantage of the MRI in patients clinically suspected of stroke who may initially had a negative CT brain.

Two patients in our study who demonstrated watershed infarction in bilateral cerebral hemispheres had a history of perioperative drop in blood pressure which corresponded with previous findings.(15)

Our study found that the incidence of stroke in aortic arch aneurysm (14/45, 31.1%) has a higher rate of stroke than aortic dissection (3/45, 6.7%), corresponding with the study of Waterford SD, *et al*., which showed incidence of stroke after TEVAR for aortic aneurysm at about 4.3%, and incidence of stroke after TEVAR for aortic dissection at about 3.2%.(16) Furthermore, the two patients in our study with aortic thoracic aneurysm who did not undergo aortic surgery also had ischemic stroke. This supports our hypothesis that the source of emboli originates from the vulnerable aortic arch atheroma.

In this study, three patients underwent mechanical thrombectomy and showed complete revascularization after the procedure. Those treatments follow the findings of Faheem S, *et al*. which show the benefits of endovascular intervention for large vessel occlusion in stroke occurring after cardiothoracic surgery.[13] In our study, the hospital mortality rate within 30 days of the patient experiencing stroke after undergoing cardiac surgery was 16.4% (10/61), which is less than other studies reporting hospital mortality rates of up to 30.0%.[10, 17] Furthermore, the overall stroke related death rate in post cardiac surgery within 30 days to be at 0.2%, which is less than previous findings which revealed a perioperative stroke related mortality after cardiac surgery within 30 days of 1.6% (52/3345).[18]

This study had several limitations, however. Firstly, it utilized a retrospective study design; therefore, there is the possibility of unavoidable selection bias. Secondly, 23 clinically suspected stroke patients with a negative initial CT scan of the brain did not have follow-up brain imaging performed; therefore, the possible highest incidence of stroke calculated by inclusion of these group of patients could be 2.5% instead of 1.8%. Thirdly, angiography imaging of the brain and neck were not performed in all patients, resulting in incomplete data to evaluate the risk factor and confirm an occlusion in the affected vascular territories. Lastly, there is no clinical record of the National Institutes of Health Stroke Scale (NIHSS) scores for the follow-up period to quantify the impairment of stroke as well as some missing intra-operative data for analysis of potential predictive factors of stroke.

## Conclusion

Our study found that incidence of stroke after cardiac surgery was 1.8%. The procedures that included carotid bypass surgery increased the incidence of stroke after cardiac surgery significantly, especially TEVAR with left subclavian artery revascularization. The most common pattern of stroke after cardiac surgery was the multiple scattered pattern in anterior and posterior circulation. The rate of overall stroke related death post cardiac surgery within 30 days was 0.2%.

## Acknowledgements

Poster presentation: The abstract was presented in virtual congress of The 13th Asian-Oceanian Congress of Neuroradiology on April 22, 2021.

The authors gratefully acknowledge Chanapong Kittayarak, MD for providing patient lists.

## Conflict of interest

All authors have no conflict of interest.

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