Perioperative Stroke

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Abstract

Purpose of Review This review overviews perioperative stroke as it pertains to specific surgical procedures.

Recent Findings As awareness of perioperative stroke increases, so does the opportunity to potentially improve outcomes for these patients by early stroke recognition and intervention.

Summary Perioperative stroke is defined to be any stroke that occurs within 30 days of the initial surgical procedure. The incidence of perioperative stroke varies and is dependent on the specific type of surgery performed. This chapter overviews the risks, mechanisms, and acute evaluation and management of perioperative stroke in four surgical populations: cardiac surgery, carotid endarterectomy, neurosurgery, and non-cardiac/non-carotid/non-neurological surgeries.

Keywords Perioperative · Postoperative · Stroke · Cardiac surgery · Carotid surgery · Neurosurgery · Non-cardiac and non-carotid surgery

Introduction

Perioperative stroke is defined as a stroke occurring within 30 days of the initial surgical procedure. The incidence of perioperative stroke varies and is dependent on the type of surgery performed. This chapter will overview perioperative stroke after cardiac surgery, carotid endarterectomy, neurosurgery, as well as non-cardiac/non-carotid/non-neurological surgeries.

Cerebrovascular Complications of Cardiac Surgery

Background

The field of heart surgery has undergone extraordinary changes over the past 70 years. Many operations that were once

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considered to be experimental are now thought routine, with thousands of open-heart procedures performed annually within the USA. Stroke is a well-known cardiac surgery complication, and is associated with longer hospital stay, higher cost, and elevated morbidity and mortality. Although refinements in technique over the years has reduced the incidence of neurological complications, the sheer number of elderly patients undergoing cardiac surgery has increased, and thus cerebrovascular complications continue to occur in this population [1, 2].

A prospective study of 16,184 consecutive heart surgery patients estimates that the overall incidence of stroke is generally 4.6%. However, the risk of ischemic stroke varies depending on the specific cardiac surgery procedure: Coronary artery bypass grafting (CABG) 3.8%; beating-heart CABG 1.9%; aortic valve surgery 4.8%; mitral valve surgery 8.8%; double or triple valve surgery 9.7%; CABG and valve surgery 7.4% [1, 3, 4•, 5]. With regard to patients undergoing combined CABG and a left-sided cardiac procedure (such as mitral or aortic valve replacement), it has been estimated that 15.8% of them have neurologic complications, which is further subdivided into 8.5% with stroke/TIA and 7.3% with new intellectual deterioration [6]. It seems apparent that combined procedures are associated with an elevated stroke risk compared with an isolated CABG. The clinical incidence of stroke does vary depending on the particular study, and there are certain reasons for this. For example, one study by Messé and colleagues, the Determining Neurologic Outcomes from

Valve Operations Study, determined that the clinical incidence of stroke after surgical aortic valve replacement was 17%; the highest reported in the literature [7]. However, it has been postulated that the likely reason for the escalated stroke rate was that a neurologist assessed the patients preoperatively and then performed serial postoperative exams. Many of the other published studies did not include serial assessment by a neurologist to screen for the development of stroke in the cardiac surgery population. In that same group of patients assessed by Messé and colleagues, the incidence of stroke reported by the surgeon to the Society of Thoracic Surgery (STS) database was 7%. Furthermore, 54% of the patients who did not have a clinical stroke did have evidence of silent cerebral emboli found with diffusion-weighted magnetic resonance imaging (DWI) [7, 8]. So clearly there are reasons for fluctuations in stroke rates in the current literature. As noted by Dr. Michael Mack, "it is evident that the harder you look, the more you will find" [8].

Perioperative stroke comprised 2 distinct phenomena: early/intraoperative and late/delayed/postoperative stroke. Early stroke is typically defined as a stroke that is identified when patients first wake from anesthesia or after they are extubated [9]. Patients with late or delayed strokes are defined as those who are normal neurologically when emerging from anesthesia, but later develop symptoms either during the hospital course or after discharge but within 30 days post-surgery. This distinction is important because early and delayed stroke after heart surgery each have unique risk factors and impacts on operative mortality as well as on long-term survival. A previous history of stroke is associated with delayed postoperative stroke, whereas off-pump CABG is inversely associated with early perioperative stroke. A 2019 meta-analysis of 36 studies found the pooled rate of perioperative stroke in cardiac surgery to be 2.03%, with the rates of early and late stroke being similar at ≈1% each [9]. Both early and delayed perioperative stroke are associated with a significant increase in both operative and late mortality, with the impact on operative mortality being significantly higher for early versus delayed stroke. For patients with perioperative stroke, the total operative mortality was 21.3% with 28.8% mortality for patients with early stroke and 17.9% mortality for patients with delayed stroke [9].

Both patient characteristics as well as intraoperative factors have been associated with a higher risk of both early and late stroke after heart surgery. Whitlock et al. analyzed 108,711 cardiac surgery patients and found that the strongest predictors of both early and late ischemic stroke were advanced age (> 65 years), a history of prior stroke or TIA, peripheral vascular disease, combined CABG and valve surgery, and valve surgery alone. Preoperative need for dialysis and new-onset atrial fibrillation were predictors for early stroke only [10]. Carotid artery stenosis is also a significant risk factor for perioperative strokes after cardiac operations [1, 4]. Other factors independently associated with ischemic stroke include arterial hypertension, emergent operative status, prolonged cardiopulmonary bypass duration, and intraoperative hypotension [11]. Lastly, use of intraoperative tranexamic acid is associated with postoperative stroke in patients undergoing cardiac surgery, especially in those undergoing valve surgery alone [12]. Regarding hemorrhagic strokes, the length of cardiopulmonary bypass time and lowered hematocrit are predictors for new cerebral microhemorrhages after heart surgery [13].

Various scoring metrics have also been assessed as predictors for the development of postoperative ischemic stroke. The Society of Thoracic Surgeons (STS) score is the preferred method to estimate preoperative risk in patients undergoing cardiothoracic surgery. However, calculating this score is time-consuming and requires the use of a computer-based calculator; thus, other scoring tools have also been assessed as predictors. In Whitlock's 2014 analysis mentioned above, a CHADS2 score of 2 or higher was also linked to an increased risk of stroke or death among all patient groups analyzed (including patients with known preexisting atrial fibrillation, patients with new-onset postoperative atrial fibrillation, and patients without any atrial fibrillation) [10]. Separate studies have also demonstrated that the STS, R2CHADS2, CADS2, and CHA2DS2VASc score also are significant predictors of postoperative outcome, including the development of stroke in heart surgery patients independent of the presence of atrial fibrillation. The STS and R2CHADS2 scores had the best overall accuracy [14••, 15].

Cardiac Surgery Procedures and Stroke

Coronary Artery Bypass Graft Surgery

The most common major cardiac surgical procedure performed is CABG. There are certain preoperative factors that specifically escalate the risk of the perioperative stroke post-CABG including older age, diabetes mellitus type II, previous stroke, smoking, hypertension, mild renal impairment, left main coronary disease, female gender, and a preoperative increase in C-reactive protein. Both prior TIA and previous preoperative stroke also increase risk of mortality in-hospital [1].

It was suggested in earlier studies that postoperative stroke rates were decreased in off-pump CABG patients compared with patients that underwent the operation in the more traditional on-pump method. This was attributed to the off-pump surgery potentially having less direct intraoperative aortic manipulation, although further data is needed [1]. One single-center 2009 study enrolling 2516 patients demonstrated that off-pump CABG decreased the incidence of early perioperative stroke. However, the risk of delayed stroke was not different when on- and off-pump CABG patients were compared

[1, 16]. In a similar trial, the 2013 CORONARY study examined 4752 patients undergoing on-pump versus off-pump CABG and found that the stroke rates at 30 days and 1 year were not different [17]. The potential ischemic stroke mechanisms in the heart surgery population are explored later in this review.

Valve Surgery: Aortic Valve Replacement and Mitral Valve Replacement

While the ischemic stroke rates in valve patients were mentioned previously, the stroke risk with these procedures is variable, depending in part on the age of the specific patient as well as which valve is intervened upon.

Aortic valve replacement (AVR): Patients in the 50–69-year age range who undergo mechanical aortic heart valve implantation have a similar stroke risk compared with those patients who received a bioprosthetic aortic heart valve, with the specific perioperative ischemic stroke risk being estimated to be between 2.3 and 4.8% [3, 18, 19].

Mitral valve replacement (MVR): One systematic meta-analysis of octogenarians undergoing MVR or mitral valve repair (MVRpr) identified 16 retrospective studies for further analysis. When data was pooled, the proportion of postoperative stroke after MVR was 4% and 3% in those patients who underwent MVRpr [20].

Carotid artery disease is also an independent risk factor that specifically escalates the perioperative stroke risk in both mitral valve and aortic valve surgery patients [21, 22].

Minimally Invasive Cardiac Surgical Procedures

Minimally Invasive Direct Coronary Artery Bypass

Further data is needed to determine whether minimally invasive direct coronary artery bypass (MIDCAB) procedures have a lessened stroke risk. One study suggested that the MIDCAB procedure could potentially lessen the periprocedural stroke risk compared with traditional off-pump CABG [23]. However, since this data was published, this particular operation has generally fallen out of favor, particularly when compared with off-pump techniques or with the robotic approach.

Minimally Invasive Mitral Valve Surgery

With regard to minimally invasive mitral valve surgery (MIMVS) and stroke, the data is also unclear. One single-center study assessing direct-access, minimally invasive mitral valve surgery identified a low rate of stroke/TIA, with only 0.28% of all patients experiencing stroke/TIA symptoms

[24]. One meta-analysis of minimally invasive mitral valve surgery by Modi et al. could not identify a difference in neurological events when comparing MIMVS and sternotomy groups [25, 26]. In contradiction, a 2010 Society of Thoracic Surgeons (STS) Database analysis revealed ischemic stroke was more common among minimally invasive mitral valve surgery patients compared with the traditional sternotomy technique [25, 27]. This increased stroke risk was thought to be linked to possible inadequate de-airing, fibrillating-heart techniques, and prolonged timing of CPB/cross-clamping [25].

Minimally Invasive Aortic Valve Replacement

The majority of studies have not demonstrated a difference in morbidity or mortality between minimally invasive aortic valve replacement (MIAVR) and conventional AVR [25].

Percutaneous Cardiac Surgical Procedures

Thoracic Endovascular Aortic Repair

The early 1990s heralded the development of thoracic endovascular aortic repair (TEVAR), a minimally invasive aortic procedure. Since that time, the popularity for this intervention has been growing, particularly for the treatment of descending thoracic aortic disease. One 2010 TEVAR meta-analysis assessing intervention in the descending thoracic aorta demonstrated a reduction in 30-day mortality and paraplegia as well as similar stroke rates in comparison with traditional open repair [25, 28]. Using TEVAR for ascending aorta repairs is also developing, despite the fact that aortic arch interventions require branched grafts and enhanced technical expertise to ensure optimal head vessel perfusion [25]. Further data is required to clarify the exact stroke rate in this population as well.

Transcatheter Aortic Valve Replacement (TAVR)

Transcatheter aortic valve replacement (TAVR) is a minimally invasive catheter-based surgery that is increasing in popularity for those patients with severe symptomatic aortic valve stenosis that are either high-risk or inoperable candidates for traditional open-heart surgery. TAVR is rapidly becoming a common cardiac procedure in the USA with annual volumes increasing from 4627 procedures at 198 sites in 2012 to > 50,000 procedures at 582 sites in 2017 [29, 30].

When the results were initially presented, the 2012 Placement of Aortic Transcatheter Valves (PARTNER) trial demonstrated that the 1-year symptomatic stroke rate in TAVR patients was twice the rate for patients who were treated with just medical therapy. The PARTNER trial reported 30-

day perioperative stroke rates of 3.8% and 5.5% for TAVR in high-risk and intermediate-risk cohorts, respectively, with procedural events being predominantly in the 1st postoperative week [31–33]. In 2015, additional data from that same trial showed that the stroke/TIA risk was relatively the same in the patients randomized to TAVR compared with the group randomized to surgical aortic valve replacement (AVR): 15.9% in the TAVR group compared with 14% in the surgical AVR group [1, 34, 35]. In 2018, additional follow-up data from the PARTNER trial was reported: Kapadia et al. (2018) analyzed risk of major stroke within 30 days and found that while the overall risk of stroke within a month was similar between surgical and transcatheter patients, the major perioperative stroke risk was lower in the TAVR patients compared with the surgical patients [36]. Of note, over the years, the symptomatic stroke incidence after TAVR has improved significantly and has been attributed to improved procedural experience as well as optimized delivery technology/valve design.

A subsequent meta-analysis did not identify a significant difference between TAVR and AVR in mortality, including stroke. The stroke incidence was not significantly different when comparing TAVR and AVR groups periprocedurally (2.6% vs. 2.3%). However, one subgroup analysis of the randomized controlled trials did identify a higher combined incidence of stroke/TIA in the TAVR patients when compared with the AVR patients [1, 19]. The Society of Thoracic Surgeons/American College of Cardiology Transcatheter Valve Therapy (STS/ACC TVT) 2013 registry of 7710 TAVR patients demonstrated the rate of ischemic stroke to be roughly 2% [37]. In comparison, the 2013 stroke rates in STS surgical valve replacement patients were between 1.1 and 7% [38, 39]. Another published large registry in 2015 identified the 1-year stroke rate at 4.1% [40].

Regarding factors that affect the ischemic stroke risk in TAVR patients, bilateral carotid artery disease is associated with an increased risk for perioperative strokes, with patients having a 5-fold greater stroke risk. In contrast, unilateral carotid artery stenosis was not a significant predictor. African American patients were also at a higher risk for cerebral infarction post-procedure [41]. Notably in this study, patients of female gender were found to have an increased risk of carotid disease [41]. Preoperative screening with carotid Doppler appears to be warranted in this population.

TAVR-Related Stroke: Specific Valves

In TAVR procedures, those valves typically are heavily calcified and can require balloon valvuloplasty prior to device placement. Edwards Lifesciences Sapien™ valve placement additionally necessitates a second balloon to be inflated specifically to expand the valve's stent support structure. In comparison, the self-expanding Medtronic CoreValve™ is

deployed directly into position from the catheter. Regardless of the specific valve selected, both valvuloplasty and valve deployment/implantation can potentially cause an atheroembolic shower of debris that can flow directly up the carotid arteries to the vasculature in the brain, causing an ischemic stroke [42]. TAVR stroke rates in CoreValve trials range from 2 to 5.8%, and in trials for Edwards Lifesciences Sapien™ valve, the stroke rate ranges from 5 to 7.8% [21, 39, 43].The CoreValve US Pivotal Trial High Risk Study identified the periprocedural rate of stroke to be 3.9% for CoreValve patients and 3.1% for those who underwent open surgery, with the respective rates of stroke in these groups escalating to 5.8 and 7% by 1 year [39]. Despite the fact that these stroke rates were higher than previously reported rates in some other earlier trials, these percentages were still comparable statistically between the surgical and TAVR groups.

Mechanism of TAVR-Induced Stroke

Irrespective of the specific heart valve used, both the valvuloplasty and valve deployment/implantation can potentially cause a shower of atheroemboli, which can flow directly up the carotid arteries to the brain, resulting in stroke [42]. Several TCD studies have visualized embolic phenomena during manipulation of catheters across the aortic valve and during valve implantation, verifying that embolism is a likely cause [41, 44]. Additionally, periprocedural hypotension may play a role as well [31, 41].

TAVR Embolic Protection Systems

Looking forward, factors that can decrease the TAVR stroke risk could potentially include improvement of risk prediction, optimization of valve system technology/technique, perisurgical medications, and using embolism protection systems [42]. A variety of embolic protection devices are currently being developed and assessed with active clinical trials. Further evaluation of neurologic outcomes and interventions with prospective study data is still needed, in addition to long-term clinical outcomes.

Mechanism of Stroke in Cardiac Surgery

Thromboembolic stroke occurs twice as often in the posterior cerebral circulation in heart surgery patients when compared with ischemic strokes that occur in the general population, likely because the cause of the strokes in the surgical population is cardioembolic in nature [45]. As mentioned previously, it is important to recognize that strokes in cardiac surgery patients can occur early/intraoperatively or delayed/postoperatively. These 2 types of strokes have different

pathophysiologic mechanisms: early/intraoperative stroke occurs primarily from aortic manipulation and subsequent atheroembolism, although intraoperative hypoperfusion can also play a role. Ulcerative aortic atherosclerotic lesions also can play a role in postoperative embolic stroke events as well, although delayed/postoperative stroke is typically linked to postoperative arrhythmias such as atrial fibrillation, hypercoagulability, or intracranial atherosclerotic disease [1]. It is important to grasp the conceptual framework of early and delayed stroke, as this facilitates implementing and evaluating tailored preventative strategies for both [9].

Early Stroke: Atherothrombotic, Hemodynamically Mediated Brain Infarcts: Hypoperfusion Stroke

There is an association between the severity and duration of intraoperative hypotension and postoperative stroke in patients undergoing cardiac surgery. A recent retrospective cohort study analyzed 7457 patients who underwent cardiac surgery requiring cardiopulmonary bypass at a tertiary center. A total of 1.5% of the patients experienced perioperative stroke, and stroke was strongly associated with sustained mean arterial pressure of less than 64 mmHg during cardiopulmonary bypass. As hypotension is a potentially modifiable risk factor for perioperative stroke, maintaining a mean arterial pressure > 64 mmHg may be an important intraoperative hemodynamic target to reduce the incidence of stroke in this population [11].

Additionally, other factors can contribute to hypoperfusion or watershed stroke. Carotid artery atherosclerotic disease has been identified as a cause for approximately one-third of CABG-related ischemic strokes [1, 4]. This knowledge has contributed to the concept that potentially the hemodynamic stress itself of the heart surgery plus the already stenotic or occluded extracranial carotid arteries results in ischemic stroke from brain hypoperfusion (Fig. 1). There is data to support this theory, as indeed, the risk of perioperative ischemic stroke from hypoperfusion does correlate with increasingly severe carotid atherosclerotic disease [1, 4]. CABG patients without significant carotid disease have a < 2% perioperative stroke risk, while those with a unilateral 50–99% stenosis have an escalating stroke risk to 3%. Additionally, CABG patients with bilateral 50–99% stenosis have an even higher perioperative stroke risk up to 5%, and those with carotid occlusion carry the highest risk at 7–11% [4]. This is the reason behind the decision to perform preoperative neck auscultation for bruits, carotid ultrasound, and other preoperative tests prior to performing CABG.

When concomitant coronary artery disease and severe carotid atherosclerosis are present, the optimal management strategy remains unclear. Although there is a paucity of randomized data, the current American College of Cardiology/ American Heart Association (ACC/AHA) guidelines do
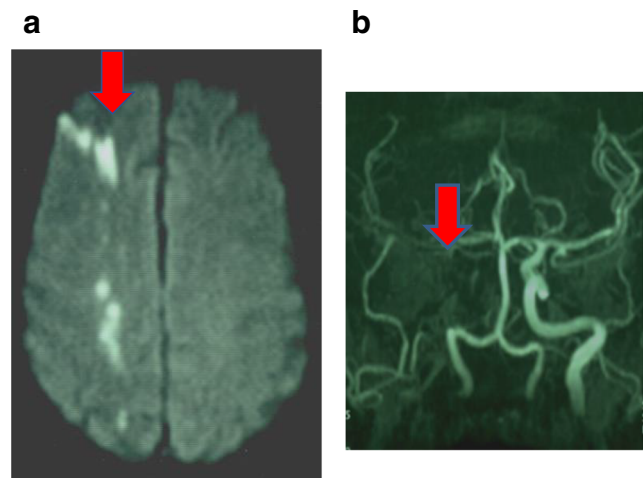
Fig. 1 a Diffusion-weighted magnetic resonance imaging (DWI) of unilateral watershed infarction that occurred in the setting of carotid stenosis. The red arrow indicates the area of acute ischemic injury positive on DWI. b Magnetic resonance angiography (MRA) in the same patient, with absence of flow in the ipsilateral intracranial carotid artery. The red arrow indicates the area of absent flow

recommend that for patients with symptomatic carotid stenosis or in asymptomatic patients with internal carotid disease of greater than 80% (unilateral or bilateral) that carotid endarterectomy (CEA) be performed either prior to or in combination with CABG. However, while both pre-CABG-CEA and combined CABG-CEA are both surgical options, there is not a clear consensus which of these two specific approaches is the superior route [1, 46]. Additionally, in surgically high-risk patients, carotid artery stenting is also an alternative carotid revascularization option, but whether pre-CABG carotid stenting should be performed also remains unclear at this time point.

Early Stroke: Cerebral Embolism

Potential hypoperfusion is not the sole early stroke mechanism in the heart surgery patient population, nor is it even the most common cause. Embolism can also be a cause of strokes intraoperatively, arising from cholesterol and/or calcific plaque atherosclerotic debris that is liberated during ascending aortic cross-clamping and/or aortotomy [1] (Fig. 2). Early perioperative strokes also tend to occur in right hemispheric locations, consistent with the direction of the aortic cannula jet flow [9, 47, 48]. As ascending aortic arch atherosclerotic disease can pose a significant perioperative stroke risk, it has been proposed that there could be an improvement in postoperative neurological outcomes by avoiding direct manipulation of this region. As a result, epiaortic ultrasound scanning was introduced as an option. Epiaortic ultrasound is currently viewed as superior to manual palpation of the ascending aortic arch as well as superior to transesophageal ECHO (TEE) in the detection of atherosclerotic disease, particularly in identifying non-
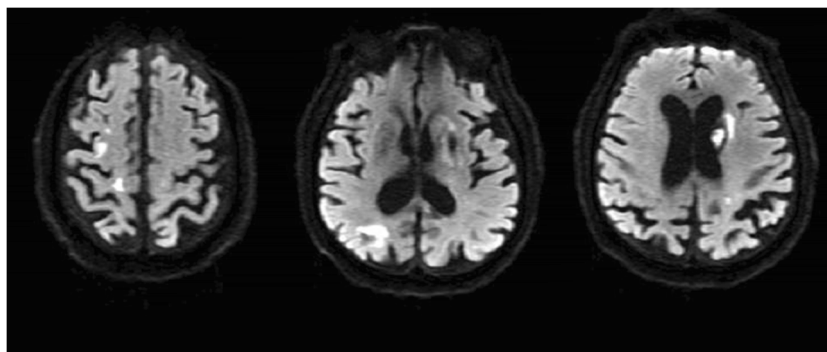
Fig. 2 Axial diffusion-weighted images demonstrate scattered foci of high signal in the subcortical and deep white matter bilaterally in a patient with a known cardiac source for embolization. Image reproduced with permission from Vinodkumar Velayudhan, DO, State University of New York Downstate Medical Center, published by Medscape Drugs & Diseases (https://emedicine.medscape.com/), Stroke Imaging, 2018, available at: https://emedicine.medscape.com/article/338385-overview

calcified plaques. This resulted in intraoperative adjustment in CABG patient management, including modifying the clamping process, cannulating, temperature control, and anastomosis techniques. Alternative surgical techniques (e.g., using in situ bilateral internal thoracic arteries and/or off-pump CABG) are also considered depending on epiaortic ultrasound scanning results [1, 49]. As a result, heart surgery patients who undergo intraoperative epiaortic ultrasound have an overall lowered stroke risk compared with other cardiac surgery patients [1, 49, 50].

Other intraoperative procedures to minimize brain injury during cardiac surgical procedures are also being assessed. For example, in both surgical and transcatheter aortic valve replacement procedures, there is strong interest in the potential use of cerebral embolic protection devices to minimize stroke risk. In general, there are two categories of cerebral embolic protection devices: embolic capture and embolic deflection, and randomized clinical trials are currently underway [8]. Additionally, left atrial appendage surgical occlusion is also associated with reduced risk of postoperative stroke and all-cause mortality in heart surgery patients. Further research in this area, however, is warranted [51].

Late Stroke: Postoperative Emboli or Hypercoagulable State

If the stroke mechanism in cardiac surgery patients was hemodynamic from suboptimal brain perfusion or embolism from cross-clamping, these infarcts would be intraoperative with deficits noted when the patient awakened from anesthesia. If patients are neurologically normal after recovering from anesthesia, typically, then there is an alternate cause. The majority of perioperative cardiac surgery strokes do tend to occur more often after full recovery from anesthesia, and these strokes typically are embolic from causes other than cross-clamping [1]. Postoperative emboli that cause late/delayed strokes can result from postoperative arrhythmias (such as atrial fibrillation), from preexisting cardiac pathology (e.g.,

dilated atria, hypofunctioning ventricles, unstable aortic atheroma), or from activating coagulation factors postoperatively. When it occurs, thromboembolic infarction typically happens during the days post-surgery when holding anticoagulation is necessary. However, optimal management of late stroke, including when or if to start anticoagulation, can be tricky. For example, in the setting of the development of postoperative atrial fibrillation, despite the plethora of blood thinning therapies available, there is little data regarding whether treatment improves clinical outcomes including stroke. Further research is warranted in this population.

Acute Ischemic Stroke Treatment in Cardiac Surgery Patients

Unfortunately, when an acute embolic stroke occurs in a cardiac surgical patient, given the recent surgery, intravenous tissue plasminogen activator (t-PA) is not a treatment option for this population. However, interventional neuroradiology procedures, including mechanical thrombectomy, can still potentially provide acute stroke treatment options for heart surgery patients; thus, rapid neurological assessment and vascular imaging should still be pursued for this reason [1].

Other Cerebrovascular Complications and Stroke Mimics

Postoperative Intracranial Hemorrhage

Rarely after cardiac surgery, intracerebral and/or subarachnoid hemorrhages have been reported, typically in cardiac transplantation patients or children that have undergone surgical repair of congenital heart disease [52, 53]. It has been theorized that these hemorrhages arise from an abrupt increase in blood flow to the brain causing rupture of small intracranial arteries that were unprepared for the new escalation of

vascular volume. Usually in these patients prior to their heart surgery, there is a prolonged period when cardiac output is low, and once the surgery has been completed, cardiac output is significantly and suddenly increased. Intracerebral hemorrhage has also been associated with abrupt increases in either brain blood flow or blood pressure in other situations [1].

Stroke Mimics: Postoperative Peripheral Nerve Complications and Other Issues

Other stroke mimics can develop after cardiac surgery as well. Brachial plexus and peripheral nerve injuries are common after heart surgery and are often confused with CNS complications. For example, a unilateral brachial plexopathy caused by either sternal retraction or arm/shoulder surgical positioning can present as shoulder pain, weakness, and numbness of one hand. Other common, positioning-related stroke mimics include ulnar, peroneal, and saphenous nerve injuries. Additionally, local effects (from compression or swelling) during heart surgery on the recurrent laryngeal and phrenic nerves can result in diaphragmatic and vocal cord paralysis. Sympathetic chain manipulation can also result in a postoperative Horner's syndrome; however, when a Horner's syndrome is detected, carotid artery dissection (particularly in surgical patients undergoing aortic dissection repair) must first be excluded before this finding can be attributed to direct manipulation [1]. Finally, both neuroleptic malignant syndrome and serotonin syndrome have been identified after heart surgery and can be related to the periprocedural administration in cardiac surgery patients who were taking antidepressants prior to surgery.

Perioperative Stroke Following Carotid Endarterectomy

Background

Perioperative stroke is the second most common cause of death after carotid endarterectomy (CEA). When considering whether CEA is indicated for a patient, the long-term benefit of future stroke reduction needs to be balanced against the risk of perioperative complications. To justify performing CEA, the overall morbidity and mortality rates associated should be low (< 6% in symptomatic patients, < 3% in asymptomatic patients) [54–56]. Of note, the morbidity and mortality rates used by the American Heart Association to formulate recommendations for undergoing CEA are more than 10 years old and based upon even older data. Two large randomized trials likely more accurately reflect the contemporary risk of perioperative stroke or death following CEA:

- The International Carotid Stenting Study (ICSS) randomly assigned 857 patients to receive carotid endarterectomy or carotid stenting for treatment of symptomatic carotid stenosis. The 120-day all-cause mortality for the symptomatic patients in the endarterectomy group was 0.8%. The 120-day combined with any stroke or procedural death rate was 4.2% [54, 57].
- The Carotid Revascularization Endarterectomy versus Stenting Trial (CREST) reported combined results for both symptomatic and asymptomatic patients. Of the 1240 patients assigned to endarterectomy (of which roughly half were asymptomatic), the 30-day death rate was 0.3%, and the rate of any periprocedural (30 day) stroke or death or post-procedural ipsilateral stroke was 2.3% [54, 58].

Stroke rates associated with CEA in other large randomized controlled trials are generally < 3% for asymptomatic patients and < 5% for symptomatic patients, with the rates ranging from less than 0.25 to greater than 3% depending upon the indication for CEA and other factors, including the experience of the surgeon [54, 59–66]. A recent 2019 meta-analysis reviewing 26 studies comparing CEA to carotid artery stenting in patients with symptomatic carotid near occlusion found that there was no significant difference between the groups in perioperative (defined as within 30 days) or long-term risk of stroke or death. Perioperative risk in the CEA cohort was noted to be 4.82% [67]. A 2017 meta-analysis of randomized controlled trials in patients with asymptomatic carotid stenosis undergoing intervention found that there was moderate-quality evidence to suggest CEA had significantly lower 30-day stroke and mortality rates compared with patients that underwent stenting, although cranial nerve injuries were higher in the surgical group. The 30-day stroke rate in the asymptomatic surgical group was 1.82% [68].

Risk Factors for Perioperative Stroke in CEA Patients

Multiple factors can contribute to postoperative stroke risk in patients who have undergone CEA. Symptomatic status, impeded cerebral hemodynamics, and increased inflammatory markers are associated with increased susceptibility to the development of acute ischemic lesions (silent stroke) on diffusion-weighted magnetic resonance imaging (DWI) postprocedure [69]. In asymptomatic patients with silent infarcts found on post-CEA DWI, risk factors were the use of a shunt and the presence of vertebral artery stenosis [70].

Other circumstances that escalate the risk of stroke and death include addition of a proximal intervention to CEA or re-operative carotid surgery [71, 72]. Severe contralateral carotid stenosis or occlusion is another risk for overall

subsequent stroke and/or death, but not for an ipsilateral stroke on the side of the endarterectomy [73]. In men with symptomatic carotid stenosis, the presence of hypercholesterolemia significantly increased the risk of perioperative stroke or death [74]. The Asymptomatic Carotid Surgery Trial (ACST-I) identified diastolic hypertension to be a risk for stroke and death, with most strokes occurring during the CEA procedure itself [75]. In asymptomatic dialysis patients, predictors of perioperative stroke were symptomatic status, black race, and Hispanic ethnicity [76]. Additional factors include plaque emboli, platelet aggregates, improper flushing, suboptimal cerebral protection, and relative hypotension [54].

Contralateral stroke after CEA is rare, affecting only 0.5% of patients. Traditional risk reduction medications such as antiplatelet do not affect the occurrence of contralateral stroke. However, the urgency of the operation, the length of the surgery, and the performance of any concomitant ipsilateral endovascular procedure do predict the development of a contralateral stroke with CEA. Contralateral stroke affects long-term survival similar to ipsilateral stroke after CE [77].

While certain factors escalate stroke risk during or post-CEA, other elements can contribute to improve outcomes. High operator volumes and high hospital volumes reduce the risk of stroke and death in CEA patients, indicating that aiming for high volumes may reduce periprocedural complications [78]. There is also a significant weekend effect in CEA patients with higher rates of stroke and death as well as prolonged length of stay in those that undergo weekend carotid operations. Thus, weekend CEA should be avoided except in the case of expedited revascularization after transient ischemic attack [79]. Additionally, preoperative administration of statins before CEA is associated with lower rates of perioperative stroke and improved overall survival [80, 81]. High intensity statin use did not show a greater outcome of stroke compared with standard use [81].

Evaluation and Treatment of Acute Ischemic Perioperative Stroke

During CEA, EEG monitoring can be useful in predicting the occurrence of a periprocedural stroke. In one cohort of 8765 patients, the perioperative stroke rate was 1.75% overall with pooled sensitivity and specificity of EEG changes in predicting these strokes at 52% and 84% respectively. CEA patients with perioperative stroke in this study had six times greater odds of experiencing an EEG change during their CEA, and continuous EEG monitoring was highly specific in predicting the development of a perioperative stroke [82]. Somatosensory evoked potentials (SSEPs) and transcranial Doppler (TCD) can also function as biomarkers for acute cerebral hypoperfusion from embolization, similar to EEG [83–85]. Additionally, TCD can adequately identify patients

at risk for cerebral hypoperfusion syndrome [84]. In the ACST-1 trial mentioned earlier in this paper, most strokes (60%) occurred on the date of the actual procedure and were caused by thrombosis or thrombotic occlusion of the ipsilateral carotid artery [86].

There is variation in the evaluation and treatment of new neurologic deficits that occur immediately following CEA. Given that postoperative neurological changes need to be first presumed to be related to the endarterectomy site, rapid assessment of the operative site is the first priority, followed by imaging to rule out intracranial hemorrhage and identify other treatable causes of acute cerebral ischemia (such as large intracranial artery occlusion from embolism). How this is accomplished depends largely upon on the availability of resources, surgeon experience, and preferences. Surgeons with access to high-quality duplex ultrasound may prefer to obtain a study in the recovery room or in the operating room, while others immediately return the patient to the operating room to explore the wound and directly inspect the endarterectomy site. If the ultrasound shows good flow throughout the carotid artery with no thrombosis or intimal flaps, a head computed tomography (CT) scan should be obtained to rule out intracranial bleeding and, if possible, a CT angiogram (CTA) done to exclude intracranial large vessel occlusion. Head CT performed immediately after an embolic event is often normal; however, a follow-up head CT after 24–48 h may reveal subsequent ischemic injury. For surgeons who have access to a hybrid operating room, another approach may be to obtain a head CT first and, if no bleeding is identified, proceed with intraoperative arteriography to identify any correctable lesions [54].

Any technical issues found at the endarterectomy site should be corrected. Carotid artery stenting may also be considered for managing perioperative stroke after CEA, particularly if the cause is a flow-limiting dissection. A small 2001 study evaluated 13 patients with major or minor neurologic complications after CEA who underwent emergency carotid arteriography and stent placement [54, 87]. The angiographic success was 100%, and 11 patients had complete resolution of neurologic symptoms. In contrast, only one of five patients undergoing surgical re-exploration had neurologic recovery. Notably, stenting is not standard for treatment of acute complications of carotid endarterectomy.

Similar to interventional treatment of cardiac surgery patients with an acute embolic stroke, given their recent surgery, CEA patients are not candidates to receive intravenous t-PA. However, these patients may still be candidates for mechanical endovascular acute stroke treatment; thus, rapid neurological assessment, consultation with neurointerventional radiology, and vascular imaging should be considered for this reason [1].

The final task is to decide on best medical therapy to prevent stroke going forwards. If tolerated, statin therapy is

recommended. For patients with ischemic strokes, antiplatelet or anticoagulation medications may be considered. Various factors come into play in choosing an antiplatelet versus an anticoagulant, including confirming stroke etiology, size of stroke, presence of hemorrhagic transformation, and other acute medical issues. The decision to heparinize the postoperative patient with new neurologic symptoms is controversial [54, 88].

Cerebral Hyperperfusion Syndrome

Cerebral hyperperfusion syndrome occurs in only a small percentage of patients after carotid revascularization (ranging from < 1 to as high as 3%) [89–92]. It is likely the cause of most postoperative intracerebral hemorrhages and seizures within the first 2 weeks after CEA.

Mechanism and risk factors

The mechanism of cerebral hyperperfusion syndrome is related to changes that occur in the ischemic or low-flow carotid vascular bed. To maintain sufficient cerebral blood flow when a tight carotid stenosis is present, small vessels in the brain compensate with chronic maximal dilatation. After surgical correction of the carotid artery stenosis, blood flow is restored to a normal or elevated perfusion pressure within the previously hypoperfused hemisphere. Unfortunately, the dilated cerebral blood vessels are thought to be unable to vasoconstrict sufficiently to protect the capillary bed because of a loss of cerebral blood flow autoregulation. Breakthrough perfusion pressure then causes edema and hemorrhage, which in turn results in the clinical symptomatology [54].

Arterial hypertension is a frequent predecessor of the syndrome, underscoring the importance of optimizing perioperative blood pressure control. Additional risks for hyperperfusion syndrome include revascularization of a high-grade (80% or greater stenosis) carotid lesion and recent preoperative cerebral infarction [54, 93–96]. In an attempt to predict the occurrence of hyperperfusion syndrome, TCD techniques have been used to monitor flow velocities of the middle cerebral artery (MCA), but the utility of TCD for this indication is not clearly established [54, 93, 97–99].

Clinical Features and Work-Up

The cerebral hyperperfusion syndrome after CEA is characterized by the following clinical features [54, 100]:

(1.) A unilateral headache ipsilateral to the revascularized internal carotid typically improved in upright posture,

and worsened when lying flat. Headache may precede the other symptomatology.
(2.) Focal motor seizures involving the face and limbs contralateral to the revascularized carotid artery. Seizures may be followed by the development of a postictal Todd's paralysis mimicking post-endarterectomy stroke.
(3.) Intracerebral hemorrhage with or without persistent focal neurological deficits is the most feared complication. Perioperative ICH occurs in an estimated 0.6% of patients after CEA, usually within 2 weeks of the surgical procedure.

Neuroimaging studies are typically performed for work-up and may include head CT and/or magnetic resonance (MR) imaging, as well as EEG. CT and MRI studies typically show cerebral edema, petechial hemorrhages, or frank intracerebral hemorrhage [54].

Treatment

The best management for cerebral hyperperfusion syndrome is prevention. Strict control of postoperative blood pressure is important. Systolic blood pressure should be maintained at or below 150 mmHg. We would recommend labetalol, and if unsuccessful, starting a nicardipine drip. Optimizing blood pressure control should begin in the operating room at the time of restoration of internal carotid flow and be maintained throughout the hospital stay as well as for the first weeks post-procedure. Postoperative blood pressure tends to be most labile in the first 24 h [54].

Any patient complaining of severe headache following CEA should be rapidly neurologically evaluated, undergo head CT, and be admitted for observation and blood pressure control as necessary. Seizures related to hyperperfusion are usually successfully treated with standard antiepileptic medication [54, 101]. In addition to controlling blood pressure, antithrombotic therapies should also be discontinued.

Stroke Mimics after CEA

Nerve injuries occur in an estimated 5% of patients following CEA. The majority of cranial nerve injuries resolve after surgery, and the risk of permanent cranial nerve deficit is low. Hypoglossal nerve injury is the most commonly reported injury, followed by the facial nerve (marginal mandibular branch) and recurrent laryngeal nerve. Risk factors for nerve injury include prolonged procedure duration, urgent procedure, the need for re-exploration (immediate or delayed), and perioperative stroke [54, 102, 103].

Perioperative Stroke Following Neurologic Surgery

Background

Perioperative neurosurgical complications can be caused by a variety of factors in the post-surgical period. Brain edema, elevated intracranial pressures, seizures, ischemic stroke, intracranial hemorrhage, and cranial nerve palsies are some of the more common complications [104–106]. Most strokes in neurosurgical patients are ischemic in origin. However, perioperative cerebral infarction in neurosurgical patients can be either arterial or venous in nature, which is a difference in this population compared with other surgical patient populations. Primary hemorrhagic strokes associated with neurological surgery are rarer.

A 2016 analysis of 94,546 patients in the American College of Surgeons National Surgical Quality Improvement Program database showed that rates of post-neurosurgical stroke have significantly decreased over time from 1.2% in 2006 to 0.5% in 2013 [107]. Despite the fact that significant ischemic and hemorrhagic strokes are both generally uncommon after craniotomies, when they do occur, the associated mortality and morbidity rates are high. Postoperative ischemic stroke with a significant, persistent neurological deficit occurs in 2% of craniotomy cases overall [105]. Between 20 and 50% of neurosurgical patients may develop early postoperative complications (including 5.7% neurological complications) and about 25% will have more than one complication [106].

Risk Factors for Perioperative Stroke in Neurosurgery Patients

Significant risk factors for the development of post-neurosurgical stroke and coma include inpatient status, age, history of diabetes mellitus, ventilator dependence, impaired sensorium, coma > 24 h, hemiparesis, recent stroke with or without neurological deficit, and central nervous system tumor [107]. Additionally, hematological risk factors such as medications (antiplatelets, anticoagulants, neoadjuvant chemotherapy), thrombocytopenia (less than 100 K), and the nature of surgery also significantly affect risk [105, 106, 108]. For example, the rate of stroke in cerebrovascular neurosurgery patients is higher at 7.3% [109].

Perioperative Predictors of Stroke Risk with Surgical Aneurysm Clipping

Patient-specific independent predictors of perioperative stroke in patients undergoing neurosurgical aneurysm clipping have also been investigated. One retrospective study in this population noted that 8% of aneurysm clipping patients develop stroke symptoms within 24 h of their neurosurgical procedure. Those patients that had intraoperative monitoring with somatosensory evoked potentials (SSEPs), and those patients with intraoperative SSEP changes were 7.33 times more likely to subsequently develop perioperative stroke. The odds of perioperative stroke were also significantly escalated in the subgroup of aneurysm patients with Hunt/Hess grade 5. Thus, in addition to intraoperative SSEP changes, the severity of the patient's preoperative subarachnoid hemorrhage is also a significant predictor of perioperative stroke [110]. A second systematic review of 14 articles confirms the utility of intraoperative SSEP monitoring in a sample population of 2015 patients, identifying that patients with postoperative neurological deficits were 7 times more likely to have intraoperative SSEP changes [111]. SSEP changes may assist in designing prevention strategies to reduce stroke rates after cerebral aneurysm clipping.

Etiology of Perioperative Stroke in Neurosurgery Patients

Ischemic stroke can result from thrombosis of a manipulated artery or vein, especially if a major venous sinus is disrupted by the craniotomy or from compromised cerebral perfusion. Arterial infarcts can occur with either traumatic laceration or sacrifice of an artery for hemostasis. This can occur in traumatic brain injuries, tumor surgery with en passant vessels and epilepsy surgery (i.e., anterior choroidal artery in temporal lobectomy). Hemorrhagic infarction from venous sinus thrombosis must also be considered in any patient suffering delayed neurological decline after a craniotomy. Venous occlusion and infarcts can occur when a bleeding vein must be coagulated during the operation itself or when massive postoperative cerebral edema leads to compressive occlusion of venous outflow. One should also be attentive to possible venous injuries in particular after meningioma or central nervous system (CNS) tumor surgery located near venous sinuses (tentorial, parasagittal, convexity, and parafalcine locations). The selection of an appropriate operative approach with the highest likelihood of preserving venous drainage structures is recommended [112]. Most often, this syndrome presents with bilateral strokes in non-vascular territories or bilateral hemorrhages. This complication is more likely following resection of a brain tumor abutting the posterior two-thirds of the superior sagittal sinus. Regarding other etiologies, perioperative stroke due to cerebral hypoperfusion is rare, but when it occurs, postoperative volume loss or dehydration can be playing a role [113].

Peri- and Postoperative Evaluation and Management

Following a neurosurgical procedure, the patient remains vulnerable to secondary cerebrovascular injury because of pathological changes associated with the disease, the nuances to the procedure itself, and the physiological changes associated with management [105]. The most important parameter to regularly monitor after elective neurosurgery is the clinical neurological exam. Additionally, in certain subpopulations such as those patients with aneurysmal subarachnoid hemorrhage, regular daily TCD monitoring is also important. TCD evidence of vasospasm is highly accurate in predicting the development of delayed cerebral ischemia [114].

When acute changes are identified, stat neuroimaging with head CT, CTA, and /or MRI should be considered. Similar to interventional treatment of cardiac and vascular surgery patients with an acute ischemic stroke, given their recent surgery, neurosurgery patients are also not candidates to receive intravenous t-PA. However, these patients too may still be candidates for mechanical endovascular acute stroke treatment; thus, rapid neurological assessment, consultation with neurointerventional radiology, and vascular imaging should be considered for this reason [1].

Neurosurgical Re-Operation: Postoperative Hematomas

Approximately 2% of patients who undergo a cranial procedure will develop a postoperative hematoma with 0.8% developing a hemorrhage that requires surgical evacuation [115]. The postoperative presentations in these patients can vary, with the most common of these being elevated intracranial pressures (if being monitored), occurring in about 90% of patients with postoperative hemorrhage. By contrast, in the absence of postoperative hematoma, only 10% of patients have elevated intracranial pressures postoperatively. About 60% of patients with postoperative hematoma present with decreased level of consciousness while 33% present with focal neurological deficits [106]. Clinically significant intracranial hemorrhage usually occurs within the first 24 to 48 h postoperatively, complicating 0.5 to 6.9% of craniotomies [116, 117]. Most patients will have a clinical change within 6-h post-surgery, although approximately 20% may develop these clinical changes after 24 h. The patients that are at particular risk for delayed hematoma are those who underwent posterior fossa surgery or emergency craniotomies. Risk factors for postoperative hematoma include meningioma surgery, intraoperative or immediate (within 12 h) postoperative hypertension, intraoperative blood loss (greater than 500 mL), age greater than 70, hypoxia, coughing and/or hiccups, and coagulopathies (elevated PTT, decreased fibrinogen or platelets)

[116–118]. Remote hemorrhages may also be noted on later imaging in postoperative neurosurgical patients (Fig. 3).

Etiologies and risk factors for postoperative hematomas include reperfusion hemorrhage releasing tamponade effect of a contralateral hemorrhage with debunking of a mass lesion, cerebrospinal fluid (CSF) drainage or hyerosmolar therapy causing a shift of parenchyma (especially in the cerebellum), and coagulopathic states.

Cerebral Hyperperfusion Syndrome

Cerebral hyperperfusion syndrome has also been reported after cerebrovascular neurosurgical procedures, particularly in patients with Moyamoya disease but has also been reported in patients with intracranial dissection that underwent arterial bypass surgery [119–122]. The presentation, etiology, and management are the same as in the vascular surgery CEA population: please note the prior section under CEA for details.

In summary, perioperative complications, especially including ischemic and hemorrhagic strokes, can occur following different types of neurosurgeries justifying an ICU postoperative stay for regular neurological monitoring and early symptom detection.

Perioperative Stroke Following Non-Cardiac, Non-Neurologic Surgery

Background

Although the incidence of clinically recognized perioperative stroke is very low after non-cardiac, non-carotid, and non-neurologic surgery, stroke remains a potentially devastating postoperative complication and an important source of perioperative mortality and morbidity [123–126]. Additionally, high surgical volumes result in thousands of these patients experiencing neurological deficits [127]. Outcome after perioperative stroke is often devastating, as perioperative stroke is associated with high rates of morbidity and mortality and increased length of hospital stay. Reported 30-day mortality after perioperative stroke related to non-cardiac, non-neurosurgical procedures is as high as 46% after general surgery, and as high as 87% in patients with a prior stroke [123–126, 128–131].

Incidence and Risk Factors

The incidence of stroke after non-cardiac, non-neurologic surgery is reported to be between 0.1 and 0.8% in registry and database studies, with the incidence of unrecognized stroke potentially being even higher [123, 124, 126, 128, 129, 132]. Perioperative stroke is significantly more common in
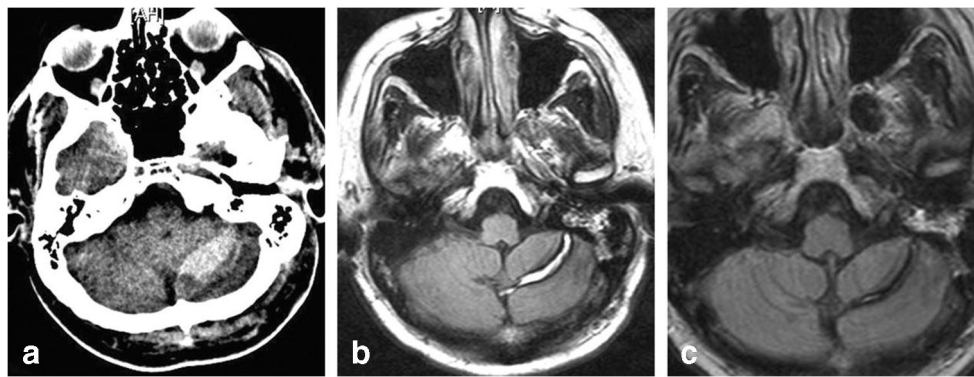
Fig. 3 Remote perioperative hemorrhage. **a** Immediate postoperative CT showing left remote cerebellar hemorrhage after resection of a supratentorial glioblastoma multiforme. Three-month follow-up MR T2-weighted (**b**) and FLAIR (**c**) images show a hemosiderin ring surrounding the resolving hematoma. Republished with permission of American Society of Neuroradiology, from "Remote cerebellar hemorrhage," Amini A, Osborn AG, McCall TD, *Am J Neuroradiol*. 2006, 27: 387–90; permission conveyed through Copyright Clearance Center, Inc.

certain surgical patient populations, even within the realm of non-cardiac, non-carotid, non-neurologic procedures. The incidence of clinically unrecognized or silent stroke after non-cardiac, non-carotid, non-neurologic surgeries is potentially as high as 7% in patients over the age of 65 [123, 133]. Risk of ischemic stroke and transient ischemic attack is increased up to 90 days after non-carotid and non-cardiac surgery [134].

Patient risk factors for perioperative stroke include atrial fibrillation, prior stroke or transient ischemic attack (TIA), age greater than 62 years, cardiovascular disease, renal disease, diabetes, chronic obstructive pulmonary disease, and female sex. Active tobacco use, obesity, and carotid artery stenosis also possibly pose risk but data is conflicting [123, 124–126, 129, 134, 135••]. Additionally, certain medications such as preoperative and intraoperative administration of beta blockers, particularly metoprolol, may increase the risk of perioperative stroke [123, 124–126, 128, 129, 132, 136–140].

History of Recent Stroke

A history of recent stroke has consistently been identified as a risk factor for perioperative stroke [123,124–126, 128, 129]. The exact time course of elevated risk of perioperative stroke after a prior stroke is uncertain, but risk is thought to be increased for at least 3 months. In part, this is based on the fact that the risk of recurrent stroke is typically high in the first few months after a TIA or ischemic stroke even without surgery and then declines over time [123, 141]. Data from a non-cardiac surgery patient registry also bears this out: a retrospective cohort study of > 480,000 patients who underwent noncardiac surgery from the Danish National Patient Register found a 67-fold increase in the risk of perioperative ischemic stroke in patients who had surgery within 3 months of an ischemic stroke, compared with patients without prior stroke [123, 128]. The perioperative stroke incidence was 12% in patients who had surgery within 3 months of an acute stroke.

This risk of perioperative stroke decreased over time after stroke and leveled off at 9 months but did remain elevated thereafter compared with patients without history of stroke [123, 128].

The authors recommend that in patients with a history of ischemic stroke, the risks of recurrent perioperative stroke should be reviewed with both the patient and the surgeon, along with the risks associated with delaying surgery. In patients with recent ischemic stroke (particularly within a 3-month period), the possibility of non-surgical treatment options or delaying elective surgery should at minimum be entertained. For urgent or emergent surgery, the risk of stroke should be part of the preoperative shared decision-making, with risks and benefits being carefully weighed and discussed.

Risks with Specific Surgical Procedures

Certain non-cardiac, non-carotid, non-neurologic surgeries have a higher risk of perioperative stroke than others (Table 1). In general, major intra-abdominal procedures (such as colectomy, hepatobiliary surgery, abdominal exploration), pulmonary resection, transplant surgery, and arthroplasty are higher-risk procedures, as is shoulder surgery in the beach chair position because of the potential for low perfusion pressures to the brain. Studies of the risk for stroke associated with non-carotid head and neck surgery are conflicting [123–126, 128, 129, 132, 142–144].

Mechanisms of Perioperative Stroke

Perioperative strokes in this surgical patient population are typically ischemic, rather than hemorrhagic. These ischemic strokes can be embolic, thrombotic, or hemodynamic (i.e., hypoperfusion of watershed areas). Cardioembolic stroke in particular is a short-term risk for perioperative stroke,

Table 1   Non-cardiac, non-carotid and non-neurologic surgeries

Surgeries escalating risk for perioperative stroke

Cardiac surgery

Carotid endarterectomy

Neurosurgery

Major vascular surgery

Major intra-abdominal procedures

Pulmonary resection

Transplant surgery

Arthroplasty

Head and neck surgery

Shoulder surgery in the beach chair position

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particularly when cessation of antiplatelet or antithrombotic medication occurs [134]. Aside from patients who clearly have an embolic stroke related to atrial fibrillation, fat embolism, or air embolism, the mechanisms for postoperative cerebral embolism or thrombosis can be unclear. Additional mechanisms for perioperative stroke may include hypercoagulability after surgery and surgery-induced inflammatory responses, but currently, there is no supporting evidence for these theories [123–126, 130, 137, 145–147]. Hypotension particularly critically reduced blood pressure also could be a source of stroke; however, the exact role of hypotension in the etiology of perioperative stroke is unclear [123, 137, 148–150].

Strategies for Stroke Risk Reduction

The most important strategies for reducing the risk of perioperative stroke in non-cardiac patients at risk for stroke include the following [123–126, 128, 129, 137, 141]:

(1.) Delaying elective surgery for at least 3 months, and if possible, up to 9 months, after an acute ischemic stroke.

(2.) Avoidance of hypotension and maintaining blood pressure within 20% of baseline blood pressure for patients at risk for perioperative stroke.

(3.) If beta-blockade is required, using cardioselective beta blockers such as esmolol or labetalol intraoperatively rather than metoprolol when possible.

(4.) Appropriate management of anticoagulation for patients with atrial fibrillation, mechanical heart valves, and other conditions that predispose them to thromboembolic stroke. The decision to continue or stop ongoing antiplatelet or anticoagulant medication in the perioperative period is a balance between reducing the risk of ischemic stroke and increasing the risk of surgical bleeding during and post-procedure. Bleeding may be catastrophic during and after intracranial and neuraxial surgery,

and discontinuation of antiplatelet and anticoagulant medications is usually warranted for these procedures. For other surgical procedures, medication management must be individualized. There may be a subset of patients at particular risk for perioperative stroke (recent ischemic stroke and/or transient ischemic attack [TIA], or existing intracranial stents) who warrant consideration for ongoing antiplatelet therapy perioperatively when the surgical procedure permits.

(5.) Postoperatively, if anticoagulation or antiplatelets are held, a date should be agreed on with the surgeon when to restart these medications, again weighing risks of ischemic stroke versus postoperative bleeding in making the decision.

In preoperative patients with prior stroke taking aspirin or warfarin, use of the American Academy of Neurology Guideline for Periprocedural Management of Antithrombotic Medications in Patients with Ischemic Cerebrovascular Disease can be helpful, as can reference to the 2017 AAC Expert Consensus Decision Pathway for Procedural Management of Anticoagulation in Patients with Nonvalvular Atrial Fibrillation. The full AAN guideline is available at www.aan.com and includes definitions of the classifications of evidence and recommendations [151, 152].

Additionally, if patients were taking statin medication prior to surgery, we recommend this be continued as well. Patients with prior stroke may be on statin medication for secondary stroke prevention. Statin withdrawal in patients with acute stroke has an 8.7-fold increased risk for early neurological deterioration and is also associated with an increased risk of death or dependency [147, 153].

Management of Acute Stroke

When acute changes are identified, stat neuroimaging with head CT, CTA, and/or MRI should be considered. Similar to interventional treatment of cardiac, vascular, and neurosurgical patients with an acute ischemic stroke, given their recent surgery, other surgery patients are also typically not candidates to receive intravenous t-PA. However, mechanical endovascular acute stroke treatment may be an option; thus, rapid neurological assessment, consultation with neurointerventional radiology, and vascular imaging should be considered for this reason [1].

Conclusion

The incidence of perioperative stroke varies and is clearly dependent on the type of surgery performed. Regardless of the type of surgery, physicians can implement diagnostic,

therapeutic, and procedural factors to optimize the perioperative risk to attempt to prevent stroke and minimize mortality and morbidity. Recognition and prevention of perioperative stroke after cardiac surgery, carotid endarterectomy, neurosurgery, as well as non-cardiac/non-carotid/non-neurological surgeries is imperative. If a neurological deficit is suspected, urgent neurological consultation should be placed to optimize care, as poor outcomes associated with stroke in these surgical populations are significant.

Compliance with Ethical Standards

Conflict of Interest   Dr. Leary has nothing to disclose. Dr. Varade has nothing to disclose.

Human and Animal Rights and Informed Consent   This article does not contain any studies with human or animal subjects performed by any of the authors.

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