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Pediatric Moyamoya Revascularization Perioperative Care: A Modified Delphi Study

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Author Contributions

LRS and LCJ conceived of the study. LRS, LCJ, ERS, PRA, and DSH designed the study and acquired the data. All authors contributed to data analysis and interpretation. LRS drafted the article and is accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of all parts of the work are appropriately investigated and resolved. All authors critically revised the manuscript for important intellectual content and approved of the version to be published. The final manuscript was approved by all authors.

Conflicts of Interest

Dr. Sun receives research funding from the Laney Jaymes Foundation for Pediatric Stroke and the American Heart Association (Career Development Award [850044]) and participates on a Data Safety Monitoring Board for StrokeNet. Dr. Jordan receives support from the National Institutes of Health (NIH K24 Hl147017). Dr. Aldana receives support from the Baptist Health Foundation and is the President of the Neurosurgery Outreach Foundation. Dr. Kirschen receives support from the National Institutes of Health. Dr. Guilliams is the Chair and Board Member of the Pediatric Neurocritical Care Research Group. Dr. Gupta receives consulting fees from Encoded Therapeutics, participates on a Data Safety Monitoring Board for the National Institutes of Health, and is on the Advisory Board of the Aneurysm and AVM Foundation. Dr. Fox receives funding from the American Heart Association and the National Institutes of Health, receives royalties from UpToDate, receives consulting fees from Competitive Drug Development International, receives honoraria for Continuum from the American Academy of Neurology, receives support for lecture travel from the Giannina Gaslini Children's Hospital, participates on a Data Safety Monitoring Board for the National Institutes of Health, and is on the PHACE syndrome Medical Advisory Board. Dr. Chung receives research funding from the National Institutes of Health (RO1 NS096714-01A1, R01 NS104094-03, 11575sc /U54NS065705) and support to attend meetings from the Pediatric Cardiac Intensive Care Society and the Neurocritical Care Society. Dr. Dirks receives research funding from the Canadian Institute of Health Research, the Canadian Cancer Society, and the Cancer Research UK Grants. Dr. Dlamini receives consulting fees from Bayer Pharmaceuticals. Dr. Pineda receives support to attend meetings from the American Board of Pediatrics. Dr. Rasmussen holds a leadership role in the Pediatric Neurocritical Care Research Group. Dr. Piatt receives consultancy fees from Power Rogers LLP (Chicago, IL) for expert testimony and participates on a Data Safety Monitoring Board related to endoscopic surgery for treatment of hydrocephalus in infancy. Dr. Lang receives research funding from the American Stroke Association Bugher Foundation, the National Institutes of Health, and the National Institute of Biomedical Imaging and Engineering, and she is a scientific co-chair for the International Society of Pediatric Neuro-Oncology. The remaining authors have no disclosures to report.

Ethical approval/informed consent

This study was deemed exempt by the Johns Hopkins Institutional Review Board (IRB00335155).

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Abstract

Background: Surgical revascularization decreases the long-term risk of stroke in children with moyamoya arteriopathy but can be associated with an increased risk of stroke during the perioperative period. Evidence-based approaches to optimize perioperative management are limited and practice varies widely. Using a modified Delphi process, we sought to establish expert consensus on key components of the perioperative care of children with moyamoya undergoing indirect revascularization surgery and identify areas of equipoise to define future research priorities.

Methods: Thirty neurologists, neurosurgeons, and intensivists practicing in North America with expertise in the management of pediatric moyamoya were invited to participate in a three-round, modified Delphi process consisting of a 138-item practice patterns survey, anonymous electronic evaluation of 88 consensus statements on a 5-point Likert scale, and a virtual group meeting during which statements were discussed, revised, and reassessed. Consensus was defined as ≥ 80% agreement or disagreement.

Results: Thirty-nine statements regarding perioperative pediatric moyamoya care for indirect revascularization surgery reached consensus. Salient areas of consensus included the following: (1) children at a high risk for stroke and those with sickle cell disease should be preadmitted prior to indirect revascularization; (2) intravenous isotonic fluids should be administered in all patients for at least 4 h before and 24 h after surgery; (3) aspirin should not be discontinued in the immediate preoperative and postoperative periods; (4) arterial lines for blood pressure monitoring should be continued for at least 24 h after surgery and until active interventions to achieve blood pressure goals are not needed; (5) postoperative care should include hourly vital signs for at least 24 h, hourly neurologic assessments for at least 12 h, adequate pain control, maintaining normoxia and normothermia, and avoiding hypotension; and (6) intravenous fluid bolus administration should be considered the first-line intervention for new focal neurologic deficits following indirect revascularization surgery.

Conclusions: In the absence of data supporting specific care practices before and after indirect revascularization surgery in children with moyamoya, this Delphi process defined areas of consensus among neurosurgeons, neurologists, and intensivists with moyamoya expertise. Research priorities identified include determining the role of continuous electroencephalography in postoperative moyamoya care, optimal perioperative blood pressure and hemoglobin targets, and the role of supplemental oxygen for treatment of suspected postoperative ischemia.

Keywords

Moyamoya disease; Cerebral revascularization; Delphi technique; Ischemic stroke; Perioperative care; Pediatric stroke; Children

Introduction

Moyamoya disease is a progressive arteriopathy that can cause disabling strokes in both children and adults and is associated with high rates of stroke recurrence [1–4]. Characterized by progressive steno-occlusive disease of the carotid terminus and its branches (and less commonly the posterior cerebral arteries) with compensatory collateral vasculature formation, moyamoya accounts for 6–10% of childhood arterial ischemic stroke [1, 2]. Moyamoya may occur in isolation or in association with a number of well-described conditions, such as sickle cell disease (SCD), Trisomy 21, and neurofibromatosis [5, 6].

Surgical revascularization for moyamoya decreases long-term stroke risk [1, 7–9], but perioperative ischemic or hemorrhagic complications occur in 10–20% of surgeries, typically within 48 h of surgery [10–14]. Because of the rarity of the disease, evidence-based approaches to safe perioperative management of children with moyamoya are limited, and a recent literature review identified substantial gaps in knowledge regarding best perioperative treatment methods [15]. Recently published Japanese guidelines and expert opinions from North America primarily focus on the importance of maintaining normotension and normocapnia [15–17]. However, clinical practices regarding perioperative moyamoya care vary substantially between providers and institutions. Particularly variable practices include antiplatelet management after surgery, sedative and vasopressor choices, intravenous fluid rates and duration, and transfusion thresholds [18].

Because of the paucity of evidence-driven practice guidelines, we sought to establish expert consensus on key components of perioperative care of children with moyamoya undergoing indirect revascularization surgery and to identify areas of equipoise requiring further research.

Methods

A modified Delphi approach was used to assess areas of consensus among a group of experts in pediatric moyamoya perioperative care. The process entailed structured rounds of anonymous questionnaires culminating in a final virtual meeting in which near-consensus statements were discussed, modified, and reassessed [19]. This study was deemed exempt by the Johns Hopkins Institutional Review Board (IRB00335155). Study data were collected and managed using REDCap electronic data capture tools hosted at Johns Hopkins [20, 21].

Expert Panel Identification

Experts in the management of pediatric moyamoya in the fields of neurology, neurosurgery, and intensive care medicine were identified through the International Pediatric Stroke Organization/International Pediatric Stroke Study moyamoya working group. Working group members identified additional experts by reputation as pediatric moyamoya specialists. Identified experts were asked to complete an eligibility survey and were invited to participate in the Delphi process if they provided medical care for children undergoing indirect revascularization surgery for moyamoya at least five times over the preceding 5 years. Participants were limited to a single expert in each discipline (neurosurgery,

neurology, intensive care) per institution to avoid results being driven by practices at a small number of institutions.

Round One: Practice Patterns Survey

Two neurologists (LRS, LCJ) and three neurosurgeons (DSH, ERS, PRA) developed a 138-item electronic practice patterns survey based on knowledge gaps identified in a literature review of perioperative care practices [15, 17]. The survey focused on care practices in the immediate perioperative period before and after indirect revascularization surgery, defined as the period when the child requires hospitalization for up to 7 days postoperatively. Topics germane to all three disciplines were included, while practices driven primarily by a single specialty (such as choice of surgical technique and intraoperative management) were not addressed. Areas with clear evidence-based practice guidelines were also omitted to focus on clinical practices guided by weak or limited data. Respondents were asked to consider general management practices for children with moyamoya arteriopathy for most items. Considerations specific to SCD or other comorbidities were specified when relevant. The anonymized survey was administered through REDCap to eligible participants in July and August 2022, and aggregate results were analyzed [18].

Round Two: Statement Assessment

Results from the practice patterns survey were used to generate 88 consensus statements (Table 1). Consensus statements were organized into six categories: Preoperative Care (10 statements), Vascular Access (9 statements), Postoperative Monitoring (10 statements), Postoperative Therapies (35 statements), Acute Neurologic Changes (18 statements), and De-escalation of Care (6 statements). In October 2022, participants completed an anonymous survey in which they rated their level of agreement with each statement on a 5-point Likert scale (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree). Consensus was defined as ≥ 80% agreement (combining strongly agree and agree) or disagreement (combining disagree and strongly disagree), near consensus as 65–79% agreement or disagreement, and lack of consensus as < 65% agreement or disagreement.

Round Three: Virtual Meeting

A synchronous virtual meeting was held in March 2023. Thirteen near-consensus statements were discussed and revised as a group (Table 2). In a final poll, respondents anonymously rated these statements on the same 5-point Likert scale using Poll Everywhere. At the conclusion of the meeting, statements achieving ≥ 80% agreement or disagreement were considered to have achieved consensus.

Results

Of 39 experts (16 neurosurgeons, 13 neurologists, and 10 intensivists) identified, 30 (13 neurosurgeons, 11 neurologists, and 6 intensivists) met eligibility criteria for requisite experience and participated in the Delphi process. Participants practiced at 21 distinct institutions throughout Canada (n = 4, 13%) and the United States, including in the Northeast (n = 7, 23%), West (n = 7, 23%), Midwest (n = 6, 20%), and South (n = 6, 20%). Most participants (90%) practiced at free-standing children's hospitals. Participants had

been practicing for a median of 9.5 years (interquartile range 6–20 years) after fellowship. Most participants (n = 21, 70%) were part of a formal multidisciplinary program for perioperative moyamoya care at their institution.

All 30 participants completed the practice patterns survey and the second round of the modified Delphi process. Of the 88 statements assessed in the second round (Table 1), 35 (39.8%) reached immediate consensus, 14 (15.9%) were near consensus, and 39 (44.3%) did not reach consensus.

Twenty-two (73%) participants (six neurosurgeons, ten neurologists, and six intensivists) attended the final virtual meeting to discuss near-consensus statements. Thirteen of the 14 near-consensus statements were discussed. The final near-consensus statement was not presented because it related to timing of central venous access discontinuation, but there was not consensus that central venous access was necessary and therefore the statement was considered irrelevant. Following the group discussion, seven statements were modified (Table 2). At the conclusion of the process, consensus was reached for 39 statements (Table 3). In the preoperative care category, 70% of statements reached consensus whereas only 30% of statements regarding postoperative monitoring reached consensus. In the remaining categories (vascular access, postoperative therapies, acute neurologic changes, and de-escalation of care), 40–50% of statements reached consensus.

Discussion

Despite the high risk of perioperative complications in children with moyamoya, data supporting specific care practices before and after surgery are lacking. In the absence of high-quality clinical research studies to guide perioperative care of children with moyamoya undergoing indirect revascularization surgery, this Delphi process defined areas of consensus among neurosurgeons, neurologists, and intensivists with moyamoya expertise and identified important areas of equipoise.

General Preoperative Considerations

- Institutional protocols should be established to alert key medical team members when a patient with moyamoya will undergo anesthesia for any reason (97% agreement).
- Patients at a high risk of stroke or transient ischemic attack (TIA) should be preadmitted for hydration prior to indirect revascularization surgery (90% agreement).
- Patients with SCD should be preadmitted for hydration and/or transfusion prior to indirect revascularization surgery (97% agreement).

A cornerstone of published perioperative care pathways is the multidisciplinary approach to perioperative care [15]. Key medical team members may vary by institution but typically include pediatric neurosurgeons, neurologists, anesthesiologists, intensivists, and nurses, with additional team members included based on patient characteristics (such as

hematologists for children with SCD). All members of the care team should be aware of management considerations unique to children with moyamoya.

While there was consensus that children deemed to be at a high risk of stroke or TIA and children with SCD should be preadmitted prior to indirect revascularization surgery, there was no consensus on whether preadmission is necessary for all children with moyamoya. Prior studies have identified young age (especially age < 3 years), posterior circulation stenosis, frequent TIAs, and stroke history as risk factors for perioperative ischemic events in children with moyamoya [11, 13, 22–24], suggesting a possible subset of patients who may benefit from preadmission for fluid, electrolyte, nutritional, and hematologic management. For patients at a lower risk of stroke and TIA, it may be possible to accomplish intravenous hydration and other optimization measures safely in the immediate preoperative period and/or in the outpatient setting.

Intravenous Hydration

- Intravenous hydration should be administered for *at least* 4 h prior to indirect revascularization surgery (80% agreement).
- Isotonic fluids are the preoperative fluid of choice for patients undergoing indirect revascularization surgery (100% agreement).
- Intravenous fluids should be continued for *at least* 24 h following indirect revascularization surgery (93% agreement).
- Normal saline is the postoperative intravenous fluid of choice following indirect revascularization surgery (84% agreement).
- When intravenous fluids are ready to be discontinued, they should be weaned while the patient’s neurological status is being monitored (80% agreement).

Perioperative hydration in children with moyamoya is widely considered standard of care, with the objective to avoid blood pressure fluctuations intraoperatively [17]. The American Heart Association/American Stroke Association 2019 statement on the management of stroke in neonates and children asserts that careful hydration, typically with an intravenous fluid rate of 1.25–1.5 times maintenance, is a key principle of perioperative care in children with moyamoya [1]. Case reports have suggested an association between dehydration and perioperative stroke [25].

Although there was consensus that intravenous hydration with isotonic fluids (with or without the addition of dextrose) should be administered for at least 4 h before surgery, some experienced, high-volume centers do not follow this practice. Whether this duration of prehydration is necessary for all patients is not known, and administration of a single intravenous fluid bolus may be sufficient or preferable to optimize cerebral perfusion pressure, at least in some patients. Targeting euvolemia may be more important than a standardized time and fluid infusion rate for intravenous hydration prior to surgery.

Although there was consensus that normal saline should be continued for at least 24 h after indirect revascularization surgery to support cerebral perfusion, there was no consensus on the rate of fluid administration or the need for titration based on urine output. Only 60% of

respondents agreed that fluids should be continued at 1.25–1.5 times the maintenance rate, which is what is suggested by the American Heart Association/American Stroke Association 2019 statement [1]. Some participants noted that they would not replace intravenous access if it were lost on the first postoperative day in an euvolemic child who is taking adequate fluids orally.

Antiplatelet Management

- Aspirin should not be held before indirect revascularization surgery (80% agreement).
- Antiplatelet therapy should resume immediately following indirect revascularization surgery assuming no significant bleeding complications during surgery (80% agreement).

Thromboembolic events are one mechanism of postoperative stroke in patients with moyamoya [26]. A recent meta-analysis demonstrated a protective effect of antiplatelet therapy against acute postoperative stroke in adults with moyamoya [27]. In another study of adults and children who underwent combined revascularization procedures (superficial temporal to middle cerebral artery direct bypass plus indirect revascularization), aspirin did not increase the risk of hemorrhagic surgical complications [28]. Concordant with these data, there was consensus that antiplatelet therapy should not be discontinued perioperatively. The role of aspirin in children with hemorrhagic stroke and moyamoya arteriopathy is an important knowledge gap, as is the optimal antiplatelet agent.

Vascular Access

- Arterial lines are necessary for blood pressure monitoring in the initial postoperative period following indirect revascularization surgery (80% agreement).
- When present following indirect revascularization surgery, arterial lines should be continued for at least 24 h postoperatively (assuming arterial line is functioning/not causing excessive discomfort or agitation; 80% agreement).
- When present following indirect revascularization surgery, arterial lines should be continued until active interventions to achieve blood pressure goals are no longer needed (assuming arterial line is functioning/not causing excessive discomfort or agitation; 100% agreement).
- *Consensus by disagreement*: When present following indirect revascularization surgery, arterial lines should be continued until the patient no longer requires intravenous opioids for pain control (81% disagreement).

The consensus that arterial lines should be continued for at least 24 h postoperatively and until active interventions to achieve blood pressure goals are no longer needed emphasizes the importance of strict postoperative blood pressure management. Hypertension and hypotension both should be avoided given the risks of surgical site hemorrhage and provocation of an ischemic event, respectively. If an arterial line malfunctions or causes excessive discomfort or agitation, the risks and benefits of replacing or continuing the line

should be assessed on a case-by-case basis. Notably, there was no consensus on whether central venous access was necessary for either all patients or high-risk patients following indirect revascularization surgery.

Despite the concern that opioid use might cause blood pressure instability, there was widespread disagreement that invasive blood pressure monitoring should be continued until opioids were no longer needed. Instead, the group preferred to focus on statements that directly addressed the necessity of active blood pressure interventions, regardless of cause.

Postoperative Monitoring

- All patients should be admitted to an intensive care unit following indirect revascularization surgery (97% agreement).
- Vital signs should be monitored hourly for *at least* 24 h following indirect revascularization surgery (100% agreement).
- Neurologic checks should be performed hourly for *at least* 12 h following indirect revascularization surgery (94% agreement).

In patients with moyamoya, ischemic strokes can be provoked by agitation and crying that result in hyperventilation and hypocarbia-associated vasoconstriction [29]. Therefore, perioperative monitoring including neurologic assessments, vital signs, and blood draws should be deliberate and judicious. Nonetheless, in the early postoperative course, hourly vital sign measurements may identify abnormalities in blood pressure or oxygenation that require intervention. Changes in a patient's neurologic examination may indicate an evolving stroke, cerebral edema, or intracranial hemorrhage, reinforcing the need for frequent bedside nursing neurologic assessments. Timing for decreasing the frequency of cardiopulmonary and neurologic monitoring should be individualized for each patient at the discretion of the treating team.

The group had an extensive discussion regarding frequency and duration of postoperative laboratory monitoring. Some participants felt that although abnormalities in electrolytes (such as hyponatremia), blood urea nitrogen and creatinine, and hemoglobin are infrequent, they provide important opportunities for intervention in vulnerable patients. There was near consensus (75% agreement) that blood counts and metabolic panels should be obtained daily for at least 2 days following indirect revascularization surgery. Some participants related that, in their experience, these abnormalities typically arise in the first 2–3 postoperative days. Although laboratory monitoring should be considered more frequently or for longer durations for unstable patients or those with other indications for monitoring, one concern was that frequent or protracted monitoring may provoke anemia. Some participants favored checking a blood count and basic metabolic panel once postoperatively and only as needed thereafter.

Continuous electroencephalography (EEG) monitoring, cerebral near-infrared spectroscopy, and routine postoperative neuroimaging can be considered based on the individual patient and clinical situation, but evidence was considered to be too limited to routinely recommend these neuromonitoring modalities. The majority (75% of the group) did not support routine

use of continuous EEG monitoring postoperatively, citing concerns that agitation could provoke hyperventilation, which in turn could lead to stroke in this population. However, some participants noted that continuous EEG may be able to detect cerebral ischemia prior to changes in the neurologic examination, providing a window for intervention and potentially allowing for decreased monitoring with examinations, vital signs, and laboratory studies. This practice is largely based on extrapolation from adult neurocritical care practice, in which EEG is used to monitor for delayed cerebral ischemia after aneurysmal subarachnoid hemorrhage based on predictable EEG responses to decreased cerebral perfusion [30]. One center recently reported early data that EEG monitoring after revascularization surgery in children with moyamoya may be a useful tool to identify early cerebral ischemia and monitor the response to blood pressure augmentation [31]. However, some participants expressed concerns about resource utilization; if continuous EEG monitoring becomes standard of postoperative moyamoya care, would that limit the number of centers capable of performing such procedures and restrict access to this critical procedure? Others felt that continuous EEG monitoring may be reasonable in some populations, such as those who are sedated and who cannot be monitored with detailed neurologic examinations. The role of continuous EEG monitoring after indirect revascularization needs to be defined better by future clinical research studies.

Blood Pressure Management

- During the initial postoperative period following indirect revascularization surgery in an asymptomatic patient, blood pressure should be kept at or above the patient's baseline blood pressure (90% agreement).
- Intravenous fluids are the first-line treatment for hypotension following indirect revascularization surgery (93% agreement).
- Vasopressors should be used to treat hypotension that is not responsive to intravenous fluids following indirect revascularization surgery (97% agreement).
- Treatment of pain and agitation is the first-line treatment for hypertension following indirect revascularization surgery (87% agreement).

Although the importance of avoiding hypotension in children with moyamoya after indirect revascularization is widely recognized [1, 15, 17], studies comparing various blood pressure goals are lacking. There was consensus that postoperative blood pressure should be maintained at or above the patient's baseline but no consensus that higher blood pressure goals are needed.

There was no consensus on specific blood pressure thresholds requiring antihypertensive treatment, including if hypertension should be treated at a specific number or percentile for age or if it should only be treated when symptomatic. The optimal antihypertensive therapy once pain and agitation are controlled was also not agreed on, although calcium channel blocker infusion and short-acting agents such as hydralazine and labetalol were considered by different participants to be first-line in the practice patterns survey.

Red Blood Cell Transfusion Thresholds

Patients with SCD

- Patients with SCD should undergo transfusion within 1 week prior to indirect revascularization surgery to attain their goal hemoglobin S (HbS) fraction (90% agreement).

Individuals with SCD with and without moyamoya are at risk of sickle-related complications following general anesthesia and surgery [32]. The Transfusion Alternatives Pre-Operatively in Sickle Cell Disease trial showed that patients with HbSS or HbSβ^0 thalassemia who received preoperative transfusion before low-risk and moderaterisk surgical procedures had fewer complications (primarily acute chest syndrome) compared with patients who did not receive a transfusion [33]. The American Society for Hematology 2020 guidelines regarding transfusions in patients with SCD suggest that exchange transfusion should be considered for individuals with SCD undergoing high-risk surgical procedures, including neurosurgery [34]. Although the optimal HbS fraction is not known in these cases, a target HbS% of < 30% has been suggested [32]. In general, for children with SCD, a preoperative hemoglobin goal of 9 g/dL is recommended by the American Society for Hematology [34], whereas a preoperative hemoglobin goal of 10 g/dL for children with SCD is suggested by the Pediatric Critical Care Transfusion and Anemia Expertise Initiative consensus recommendations [35]. The optimal target hemoglobin and HbS% may differ in patients with SCD and moyamoya because of differences in autoregulation capacity and stroke risk; this is an important area for future investigation.

Patients Without SCD—There is less consensus in the literature and among our participants about transfusion thresholds in individuals without SCD. In a study comparing liberal red blood cell (RBC) transfusion thresholds (hemoglobin 9.5 g/dL) with restrictive thresholds (hemoglobin 7 g/dL) in stable, critically ill children, a hemoglobin threshold of 7 g/dL was associated with decreased transfusion requirements without more adverse events [36]. Recent guidelines from the Pediatric Critical Care Transfusion and Anemia Expertise Initiative recommend not transfusing critically ill children if hemoglobin is ≥ 7 g/dL, including those children with acute postoperative nonhemorrhagic anemia, and they did not find sufficient evidence to support a transfusion threshold in critically ill children with hemoglobin between 5 and 7 g/dL [35]. The same guidelines recommend considering transfusion in critically ill children with acute brain injury including stroke when their hemoglobin is between 7 and 10 g/dL. Importantly, these studies and guidelines do not specify exceptions or considerations for children with cerebral arteriopathies. Tolerance of anemia is likely different in children with moyamoya, who may have altered cerebral blood flow and autoregulatory capacity and may therefore be more vulnerable to decreases in oxygen carrying capacity.

Studies defining optimal transfusion thresholds in children with moyamoya are sparse. One study of 659 children undergoing indirect revascularization procedures for moyamoya in Korea found that immediate post-operative hemoglobin > 13 g/dL was associated with a lower risk of perioperative infarction [37]. In 24 adults undergoing direct revascularization for moyamoya at a single center in the United States, postoperative hemoglobin < 10 g/dL

was associated with neurologic events in the first 24 h after surgery [38]. Analysis of a large readmission database showed that the rate of perioperative stroke in patients with moyamoya was higher in patients with anemia compared with those without anemia [39].

There was no consensus regarding the lower limit of acceptable hemoglobin values in children without SCD after indirect revascularization surgery for moyamoya. After extensive discussion in the final round, 75% of respondents agreed that hemoglobin should be maintained above 8 g/dL postoperatively (from 66% agreement in round two), but consensus was not achieved. Participants agreed that a hemoglobin threshold exists and likely should be higher in children with moyamoya than the standard critical care threshold of 7 g/dL, but the group did not feel there were adequate data available to define what that threshold should be in this population. Additional points of discussion included the idea that no single optimal threshold may be appropriate for all children with moyamoya, as individualized thresholds could depend on the degree of arterial stenosis, which would impact reliance on arterial oxygen content to maintain cerebral oxygen delivery.

Other Tenets of Postoperative Care

- Pain should be minimized following indirect revascularization surgery (100% agreement).
- Oxygen saturation should be kept > 95% following indirect revascularization surgery (90% agreement).
- Normothermia should be maintained following indirect revascularization surgery (84% agreement).
- Following indirect revascularization surgery, antiseizure medications are not required to be prophylactically administered to all patients not already on baseline antiseizure medication (94% agreement).
- Following indirect revascularization surgery, antiseizure medications should be continued for patients who were taking antiseizure medications preoperatively (100% agreement).
- Patients may participate in physical and/or occupational therapy as soon as they are medically stable following indirect revascularization surgery (93% agreement).

Postoperative care focuses on stroke prevention by optimizing cerebral perfusion and oxygen delivery, minimizing metabolic demand, and avoiding pain and agitation. Although there was consensus on the need for pain control, there was no agreement on specific pain or agitation treatments. The lack of consensus likely reflects that the best analgesic agent may vary by patient characteristics and stability, as well as availability. Specific agents can be chosen based on the patient's severity of pain, the need to preserve mental status, and the patient's hemodynamic stability.

Up to 20% of children with moyamoya have epilepsy [40]. There was consensus that antiseizure medications should be continued postoperatively if a child was on the medication

preoperatively but that they do not routinely need to be initiated prophylactically in children not on antiseizure medications at baseline.

Notably, there was no consensus regarding the role of incentive spirometry in the postoperative period, which may reflect concerns about hyperventilation-induced cerebral vasoconstriction and stroke. There was also no consensus regarding the necessity of prophylactic antibiotics or scheduled antiemetics after indirect revascularization. Further studies should evaluate the role of scheduled antiemetics to reduce agitation, discomfort, and retching postoperatively.

When indicated, physical and/or occupational therapy is reasonable when patients are awake, alert, and hemodynamically stable. Early mobilization has been shown to be safe in other cohorts of critically ill children [41], and the risks and benefits of early mobilization after moyamoya revascularization surgery are an area for future exploration.

Acute Neurologic Changes

Indications for Emergent Neuroimaging

- Emergent neuroimaging should be obtained for new focal weakness, sensory changes, or aphasia following indirect revascularization surgery (97% agreement).
- Emergent neuroimaging should be obtained for any first-time seizure or seizure of new semiology following indirect revascularization surgery (94% agreement).
- Emergent neuroimaging should be obtained for new severe headache following indirect revascularization surgery (83% agreement).
- Emergent neuroimaging should be obtained for decreased level of responsiveness following indirect revascularization surgery (80% agreement).
- *Consensus by disagreement*: Emergent neuroimaging should be obtained for isolated tachycardia following indirect revascularization surgery (100% disagreement).

There was broad agreement that children experienc ing their first lifetime seizure or a seizure with semiology different from their baseline seizures should undergo emergent neuroimaging to evaluate for new stroke, intracranial hemorrhage, or cerebral edema. However, there was no consensus on whether emergent neuroimaging should be routinely obtained when a patient with preexisting epilepsy has a typical seizure in the postoperative period. Some participants advocated for emergent imaging at least once if this occurs, whereas others felt it was prudent to consider the seizure type, frequency of baseline seizures, and other clinical parameters such as the examination and vital signs. There was broad agreement at the conclusion of the discussion that patients should be carefully assessed with every change in neurologic status and the appropriateness of imaging will vary based on clinical circumstances.

Management of Acute Neurologic Changes

- An intravenous fluid bolus should be administered to patients with a new focal neurological deficit following indirect revascularization surgery (100% agreement).
- An intravenous fluid bolus should be the first intervention for patients with a new focal neurological deficit following indirect revascularization surgery (80% agreement).
- Supplemental oxygen could be trialed to treat new focal neurological deficits postoperatively, even in the absence of hypoxemia (84% agreement).

Although there was broad support for an intravenous fluid bolus being the first intervention for patients with new focal neurologic deficits postoperatively, there was otherwise little consensus regarding how to treat new neurologic deficits. This likely reflects the broad range of possible causes of new deficits after surgery, including ischemic stroke/TIA, intracranial hemorrhage, and seizure, and the perspective that the approach to new deficits should be multipronged and personalized based on the deficit etiology, time from surgery, medical comorbidities, cardiopulmonary status, vascular access, and other factors. Each of the potential interventions queried—flat head of bed, RBC transfusion, loading dose of antiplatelet agent, antiseizure medication, vasopressors—may be appropriate under the right clinical circumstances.

There was considerable discussion about the role of supplemental oxygen in a normoxic patient with new deficits. Several participants cited experience using oxygen to relieve headache in children with moyamoya and asked whether increased oxygen delivery could alleviate ischemic symptoms, as well. Although this is an area for future research, there was consensus that in the absence of controlled studies, supplemental oxygen could be trialed for new neurologic deficits, even in the absence of hypoxemia, as part of a broader approach to assess and treat the patient. Notable exceptions may include patients with pulmonary or cardiac disease for whom supplemental oxygen may be contraindicated.

De-escalation of Care

- Patients should be observed in an intensive care setting for at least 24 h following indirect revascularization surgery (90% agreement).
- Before transitioning out of the intensive care setting following indirect revascularization surgery, the patient should be meeting his or her blood pressure goals without vasopressors (93% agreement).
- Before being discharged following indirect revascularization surgery, patients should be observed in the hospital for a minimum of 24 h (inclusive of time in the intensive care unit; 100% agreement).

Limited data suggest that more than half of postoperative strokes occur in the first 24 h after surgery [26], although most studies define the postoperative period as the first 7–30 days after surgery. These data are concordant with our group’s consensus that patients should be observed in an intensive care setting for at least 24 h after indirect revascularization.

Research Priorities

Important knowledge gaps were identified, with several research priorities emerging from discussion or significant equipoise. These include:

1. Multimodal neuromonitoring in the postoperative period after indirect revascularization surgery. The use of multimodal monitoring in pediatric neurocritical care is expanding, but practices remain variable among institutions [42, 43]. Limited data support continuous EEG as a mechanism for early detection of ischemia [31], but its sensitivity and specificity, ability to supplant other forms of monitoring, and time course of ischemia detection remain unknown.
2. Optimal blood pressure goals. A blood pressure range, either based on the patient's baseline blood pressure or age-based normative values, that minimizes the risk of hemorrhage while ensuring adequate cerebral perfusion needs to be defined. The severity of stenosis, comorbid conditions, postoperative course, and whether the patient had preceding ischemic or hemorrhagic brain injury may influence individualized blood pressure targets.
3. Postoperative RBC transfusion thresholds. Although there was consensus that preventing, monitoring for, and treating anemia are important to optimize neurologic outcomes in children with moyamoya, no specific threshold for transfusion could be defined due to lack of adequate data in this population.
4. Role of hyperoxia in treatment of postoperative focal neurologic deficits. Whether supplemental oxygen to increase partial pressure of oxygen provides benefit when part of a multimodal treatment strategy for postoperative ischemia is an important area for further investigation.

Multiple knowledge gaps regarding the care of children with moyamoya outside of the perioperative period also emerged. These include the role of aspirin in patients with moyamoya and hemorrhagic stroke, patient selection and timing of surgery, best antithrombotic management, best treatments of moyamoya-related headache, and optimal timing and modality of long-term follow-up neuroimaging. Furthermore, the specific care of children with SCD, although not the primary focus of this consensus process, was clearly of importance to respondents and requires further investigation.

Limitations

The Delphi consensus process is designed to elicit expert opinion on topics with limited data. As such, statements reaching consensus are merely the opinions of this group of experts and are not evidence-based guidelines or standards of care. The discussion sparked by this collaborative effort is meant to encourage future clinical research studies. Furthermore, the selection of experts was based on participation in a moyamoya working group and/or reputation as a pediatric moyamoya expert; the expert panel was not inclusive of all health care providers with moyamoya expertise. Conclusions might differ if a different set of respondents was included. Additionally, in the final virtual meeting, only 46% of participating neurosurgeons were present compared with 90% of neurologists and 100% of

intensivists. Therefore, the conclusions regarding some statements may have been different if broader attendance had been achieved. The responses were anonymous, so it was not possible to determine whether trends or differences in responses exist among neurosurgeons, neurologists, and intensivists.

In addition, pediatric moyamoya arteriopathy is a heterogenous entity. Differences in arteriopathy severity, degree of preoperative ischemia, age at presentation, and syndromic associations have all been shown to impact disease course and outcomes [5, 6, 44]. The statements presented to respondents were generalizations and could not account for these and other important baseline differences as well as a multitude of clinical factors that can and should impact clinical decision-making. Therefore, bedside assessment should supersede these general statements, when appropriate.

Conclusions

Although surgical revascularization decreases the long-term risk of stroke and improves functional and cognitive outcomes in children with moyamoya [1, 7–9], optimal perioperative management is critical due to the 10–20% risk of perioperative vascular complications [10–14]. This Delphi process identified areas of consensus and several areas of equipoise that warrant further investigation. These statements comprise expert opinion and define areas of future study, but they do not constitute evidence-based guidelines nor standard of care. Future investigation should focus on evaluating the practices defined here and explore the role of EEG and other postoperative neuromonitoring techniques, optimal blood pressure parameters and RBC transfusion thresholds, and the role of oxygen supplementation in treating perioperative ischemia.

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Table 1

Consensus statements presented in Delphi round two (electronic survey)

Preoperative care
1. Institutional protocols should be established to alert key medical team members when a patient with moyamoya will undergo anesthesia for any reason
2. Aspirin should not be held before indirect revascularization surgery
3. All patients should be preadmitted for optimization prior to indirect revascularization surgery
4. Patients with sickle cell disease should be preadmitted for hydration and/or transfusion prior to indirect revascularization surgery
5. Patients at high risk of stroke or TIA should be preadmitted for hydration prior to indirect revascularization surgery
6. Intravenous hydration should be administered for AT LEAST 4 h prior to indirect revascularization surgery
7. Intravenous hydration should be administered for AT LEAST 12 h prior to indirect revascularization surgery
8. Normal saline is the preoperative intravenous fluid of choice for patients undergoing indirect revascularization surgery
9. Patients with sickle cell disease should undergo transfusion within 1 week of indirect revascularization surgery to attain their goal HbS fraction
10. A baseline EEG should be obtained prior to indirect revascularization surgery
Lines and access
11. Central venous access is necessary for all patients during the initial postoperative period following indirect revascularization surgery
12. Central venous access is necessary for patients at high risk of stroke or TIA in the initial postoperative period following indirect revascularization surgery
13. When present following indirect revascularization surgery, central venous access should be continued for at least 24 h postoperatively[a]
14. When present following indirect revascularization surgery, central venous access should be continued until blood pressure goals are met with oral medications[a]
15. When present following indirect revascularization surgery, central venous access should be continued until the patient no longer requires IV opioids for pain control[a]
16. Arterial lines are necessary for blood pressure monitoring in the initial postoperative period following indirect revascularization surgery[a]
17. When present following indirect revascularization surgery, arterial lines should be continued for at least 24 h postoperatively[a]
18. When present following indirect revascularization surgery, arterial lines should be continued until blood pressure goals are met with oral medications[a]
19. When present following indirect revascularization surgery, arterial lines should be continued until the patient no longer requires IV opioids for pain control[a]
Postoperative monitoring
20. All patients should be admitted to an intensive care unit following indirect revascularization surgery
21. Continuous EEG monitoring should be routinely performed during the initial postoperative period following indirect revascularization surgery
22. Cerebral near-infrared spectroscopy should be routinely performed during the initial postoperative period following indirect revascularization surgery
23. Routine postoperative imaging should be performed during the initial hospitalization following indirect revascularization surgery
24. Vital signs should be monitored hourly for AT LEAST 24 h following indirect revascularization surgery
25. Neuro checks should be performed hourly for AT LEAST 6 h following indirect revascularization surgery

26. Neuro checks should be performed hourly for AT LEAST 12 h following indirect revascularization surgery

27. Neuro checks should be performed hourly for AT LEAST 24 h following indirect revascularization surgery

28. Laboratory studies (including blood counts and a metabolic panel) should be obtained AT LEAST every 12 h while the patient is in the ICU following indirect revascularization surgery

29. Laboratory studies (including blood counts and a metabolic panel) should be obtained AT LEAST daily while the patient is in the ICU following indirect revascularization surgery

Postoperative therapies

30. Antiplatelet therapy should resume immediately following indirect revascularization surgery (assuming no significant bleeding complications during surgery, whether or not held preoperatively)

31. IV fluids should be continued for AT LEAST 24 h following indirect revascularization surgery

32. IV fluids should be continued for AT LEAST 48 h following indirect revascularization surgery

33. When IV fluids are ready to be discontinued, they should be weaned while the patient's neurological status is being monitored

34. Normal saline is the postoperative IV fluid of choice following indirect revascularization surgery

35. In the normotensive patient, IV fluids should be administered at maintenance rate in the immediate postoperative period following indirect revascularization surgery

36. In the normotensive patient, IV fluids should be administered at 1.25–1.5 times maintenance rate In the Immediate postoperative period following Indirect revascularization surgery

37. Fluid rate should be adjusted based on standard urine output goals

38. Pain should be minimized following indirect revascularization surgery

39. Opioids should be used to treat agitation in the postoperative period following indirect revascularization surgery

40. Dexmedetomidine should be used to treat agitation in the postoperative period following indirect revascularization surgery

41. Following indirect revascularization surgery, antiseizure medications should be prophylactically administered to all patients

42. Following indirect revascularization surgery, antiseizure medications should be continued for patients who were taking antiseizure medications preoperatively

43. During the initial postoperative period following indirect revascularization surgery in an asymptomatic patient, blood pressure should be kept at or above the patient's baseline blood pressure

44. During the initial postoperative period following indirect revascularization surgery in an asymptomatic patient, blood pressure should be kept ~ 10% above the patient's baseline blood pressure

45. During the initial postoperative period following indirect revascularization surgery in an asymptomatic patient, blood pressure should be kept at or above the 50th percentile (based on age/sex/height)

46. During the initial postoperative period following indirect revascularization surgery in an asymptomatic patient, a mean arterial pressure of 70–90 mm Hg should be maintaine

47. IV fluids are the first-line treatment for hypotension following indirect revascularization surgery

48. Vasopressors should be used to treat hypotension that is not responsive to IV fluids following indirect revascularization surgery

49. Following indirect revascularization surgery, in the absence of a new stroke, TIA, or intracranial hemorrhage, hypertension should be treated when the blood pressure is > the 95th percentile (based on age/sex/height)

50. Following indirect revascularization surgery, in the absence of a new stroke, TIA, or intracranial hemorrhage, hypertension should be treated when the blood pressure is > 15% above the 95th percentile (based on age/sex/height)

51. Following indirect revascularization surgery, in the absence of a new stroke, TIA, or intracranial hemorrhage, hypertension should be treated when the mean arterial pressure is > 20 mmHg above the preoperative baseline

52. Following indirect revascularization surgery, in the absence of a new stroke, TIA, or intracranial hemorrhage, hypertension should be treated only when causing symptoms

53. Treatment of pain and agitation is the first-line treatment for hypertension following indirect revascularization surgery

54. When pain and agitation are controlled, a calcium channel blocker infusion should be used to treat hypertension following indirect revascularization surgery

55. When pain and agitation are controlled, short-acting agents (e.g., hydralazine and/or labetalol) should be used to treat hypertension following indirect revascularization surgery

56. In patients without sickle cell disease, the hemoglobin should be maintained above 10 g/dL following indirect revascularization surgery
57. In patients without sickle cell disease, the hemoglobin should be maintained above 8 g/dL following indirect revascularization surgery
58. In patients without sickle cell disease, the hemoglobin should be maintained above 7 g/dL following indirect revascularization surgery
59. Patients may participate in physical and/or occupational therapy as soon as they are medically stable following indirect revascularization surgery
60. Prophylactic antibiotics should be administered for 24 h following indirect revascularization surgery
61. Antiemetics should be administered on a scheduled basis for at least 24 h following indirect revascularization surgery
62. Incentive spirometry should be performed for at least 24 h following indirect revascularization surgery
63. Normothermia should be maintained following indirect revascularization surgery
64. Oxygen saturation should be kept > 95% following indirect revascularization surgery

Acute neurologic changes

65. Emergent neuroimaging should be obtained for new focal weakness, sensory changes, or aphasia following indirect revascularization surgery
66. Emergent neuroimaging should be obtained for new severe headache following indirect revascularization surgery
67. Emergent neuroimaging should be obtained for any seizure following indirect revascularization surgery
68. Emergent neuroimaging should be obtained for any first-time seizure or seizure of new semiology following indirect revascularization surgery
69. Emergent neuroimaging should be obtained for decreased level of responsiveness following indirect revascularization surgery
70. Emergent neuroimaging should be obtained for isolated bradycardia following indirect revascularization surgery
71. Emergent neuroimaging should be obtained for isolated tachycardia following indirect revascularization surgery
72. Flat head of bed position should be considered to treat new focal neurological deficits postoperatively
73. Supplemental oxygen by nasal cannula should be considered to treat new focal neurological deficits postoperatlvely
74. An IV fluid bolus should be administered to patients with a new focal neurological deficit following indirect revascularization surgery
75. An IV fluid bolus should be the first intervention for patients with a new focal neurological deficit following indirect revascularization surgery
76. A red blood cell transfusion should be considered for patients with a new focal neurological deficit following indirect revascularization surgery
77. A loading dose of an antiplatelet agent should be considered for patients with a new focal neurological deficit following indirect revascularization surgery
78. Antiseizure medication should be considered for patients with a new focal neurological deficit following indirect revascularization surgery
79. In the absence of intracranial hemorrhage, vasopressors should be used to raise the blood pressure in patients with a new focal neurological deficit following indirect revascularization surgery
80. When vasopressors are used in a patient with a new focal neurological deficit following indirect revascularization surgery, norepinephrine should be used as a first-line agent
81. When vasopressors are used in a patient with a new focal neurological deficit following indirect revascularization surgery, phenylephrine should be used as a first-line agent
82. When vasopressors are used in a patient with a new focal neurological deficit following indirect revascularization surgery, dopamine should be used as a first-line agent

De-escalation of care

83. Patients should be observed in an intensive care setting for at least 24 h following indirect revascularization surgery
84. Before transitioning out of the intensive care setting following indirect revascularization surgery, the patient should be meeting his or her blood pressure goals without vasopressors
85. Before transitioning out of the intensive care setting following indirect revascularization surgery, the patient should be meeting his or her blood pressure goals without IV fluids

86. Before being discharged following indirect revascularization surgery, patients should be observed in the hospital for a minimum of 24 h (inclusive of time in the ICU)

87. Before being discharged following indirect revascularization surgery, patients should be observed in the hospital for a minimum of 48 h (inclusive of time in the ICU)

88. Before being discharged following indirect revascularization surgery, patients should be observed for a minimum of 12 h without IV fluids

EEG electroencephalography, *ICU* intensive care unit, *IV* intravenous, *TIA* transient ischemic attack

[a] Assuming the line is functioning appropriately and not causing excessive discomfort or agitation

Table 2

Revisions to statements discussed in Delphi round three (synchronous virtual meeting)

Original statement	Revised statement(s) (% agreement)
All patients should be preadmitted for optimization prior to indirect revascularization surgery	All patients should be preadmitted prior to indirect revascularization surgery (62% agreement)
Normal saline is the preoperative intravenous fluid of choice for patients undergoing indirect revascularization surgery	Isotonic fluids are the preoperative fluid of choice for patients undergoing indirect revascularization surgery (100% agreement)
When present following indirect revascularization surgery, arterial lines should be continued until blood pressure goals are met with oral medications[a]	When present following indirect revascularization surgery, arterial lines should be continued until active interventions to achieve blood pressure goals are no longer needed[a] (100% agreement)
Laboratory studies (including blood counts and a metabolic panel) should be obtained AT LEAST daily while the patient is in the ICU following indirect revascularization surgery	Blood counts and metabolic panel should be obtained daily for AT LEAST the first 2 postoperative days following indirect revascularization surgery (75% agreement)
Emergent neuroimaging should be obtained for any seizure following indirect revascularization surgery	In a patient with preexisting epilepsy, emergent neuroimaging should be obtained for a typical seizure following indirect revascularization surgery (23% agreement)
Following indirect revascularization surgery, antiseizure medications should be prophylactically administered to all patients not already on baseline antiseizure medications	Following indirect revascularization surgery, antiseizure medications are not required to be prophylactically administered to all patients not already on baseline antiseizure medications (94% agreement)
Supplemental oxygen should be considered to treat new focal neurological deficits postoperatively, even in the absence of hypoxemia	Supplemental oxygen *should* be trialed to treat new focal neurological deficits postoperatively, even in the absence of hypoxemia (54% agreement)
	Supplemental oxygen *could* be trialed to treat new focal neurological deficits postoperatively, even in the absence of hypoxemia (84% agreement)

Thirteen of the 14 near-consensus statements were discussed. The final near-consensus statement was not presented because it related to timing of central venous access discontinuation, but there was not consensus that central venous access was necessary and therefore the statement was considered irrelevant. Seven of 13 statements discussed (54%) were modified

[a] Assuming the line is functioning appropriately and not causing excessive discomfort or agitation

Table 3

Perioperative moyamoya care Delphi statements that reached consensus

Statements	Summary	Response (%)				
		Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Preoperative care						
1. Institutional protocols should be established to alert key medical team members when a patient with moyamoya will undergo anesthesia for any reason	97% agreement	67	30	0	3	0
2. Aspirin should not be held before indirect revascularization surgery	80% agreement	30	50	17	3	0
3. Patients with sickle cell disease should be preadmitted for hydration and/or transfusion prior to indirect revascularization surgery	97% agreement	67	20	10	3	0
4. Intravenous hydration should be administered for AT LEAST 4 h prior to indirect revascularization surgery	80% agreement	20	60	5	15	0
5. Isotonic fluids are the preoperative fluid of choice for patients undergoing indirect revascularization surgery	100% agreement	80	20	0	0	0
6. Patients at high risk of stroke or TIA should be preadmitted for hydration prior to indirect revascularization surgery	90% agreement	70	20	3	3	3
7. Patients with sickle cell disease should undergo transfusion within 1 week of indirect revascularization surgery to attain their goal HbS fraction	90% agreement	43	47	10	0	0
Vascular access						
8. Arterial lines are necessary for blood pressure monitoring in the initial postoperative period following indirect revascularization surgery	80% agreement	50	30	10	10	0
9. When present following indirect revascularization surgery, arterial lines should be continued for at least 24 h postoperatively[a]	80% agreement	37	43	13	7	0
10. When present following indirect revascularization surgery, arterial lines should be continued until active interventions to achieve blood pressure goals are no longer needed[a]	100% agreement; *revised statement*	33	67	0	0	0
11. When present following indirect revascularization surgery, arterial lines should be continued until the patient no longer requires IV opioids for pain control	81% disagreement; *revised statement*	0	5	14	52	29
Postoperative monitoring						
12. All patients should be admitted to an intensive care unit following indirect revascularization surgery	97% agreement	80	17	0	3	0
13. Vital signs should be monitored hourly for AT LEAST 24 h following indirect revascularization surgery	100% agreement	73	27	0	0	0
14. Neuro checks should be performed hourly for AT LEAST 12 h following indirect revascularization surgery	94% agreement	57	37	0	7	0
Postoperative therapies						
15. Antiplatelet therapy should resume immediately following indirect revascularization surgery assuming no significant bleeding complications during surgery, whether or not held preoperatively	80% agreement	33	47	20	0	0

Statements	Summary	Response (%)				
		Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
16. IV fluids should be continued for AT LEAST 24 h following indirect revascularization surgery	93% agreement	53	40	0	7	0
17. When IV fluids are ready to be discontinued, they should be weaned while the patient's neurological status is being monitored	80% agreement	33	47	13	7	0
18. Normal saline is the postoperative IV fluid of choice following indirect revascularization surgery	84% agreement	27	57	17	0	0
19. Pain should be minimized following indirect revascularization surgery	100% agreement	67	33	0	0	0
20. Following indirect revascularization surgery, antiseizure medications are not required to be prophylactically administered to all patients not already on baseline antiseizure medication	94% agreement	61	33	0	6	0
21. Following indirect revascularization surgery, antiseizure medications should be continued for patients who were taking antiseizure medications preoperatively	100% agreement	70	30	0	0	0
22. During the initial postoperative period following indirect revascularization surgery in an asymptomatic patient, blood pressure should be kept at or above the patient's baseline blood pressure	90% agreement	33	57	3	7	0
23. IV fluids are the first-line treatment for hypotension following indirect revascularization surgery	93% agreement	23	70	7	0	0
24. Vasopressors should be used to treat hypotension that is not responsive to IV fluids following indirect revascularization surgery	97% agreement	27	70	0	3	0
25. Treatment of pain and agitation is the first-line treatment for hypertension following indirect revascularization surgery	87% agreement	27	60	10	3	0
26. Patients may participate in physical and/or occupational therapy as soon as they are medically stable following indirect revascularization surgery	93% agreement	30	63	3	3	0
27. Normothermia should be maintained following indirect revascularization surgery	84% agreement	27	57	13	0	3
28. Oxygen saturation should be kept > 95% following indirect revascularization surgery	90% agreement	40	50	10	0	0
Acute neurologic changes						
29. Emergent neuroimaging should be obtained for new focal weakness, sensory changes, or aphasia following indirect revascularization surgery	97% agreement	70	27	3	0	0
30. Emergent neuroimaging should be obtained for new severe headache following indirect revascularization surgery	83% agreement	43	40	10	3	3
31. Emergent neuroimaging should be obtained for any first-time seizure or seizure of new semiology following indirect revascularization surgery	94% agreement	57	37	0	7	0
32. Emergent neuroimaging should be obtained for decreased level of responsiveness following indirect revascularization surgery	80% agreement	47	33	17	3	0
33. Emergent neuroimaging should be obtained for isolated tachycardia following indirect revascularization surgery	100% disagreement	0	0	0	88	12

Statements	Summary	Response (%)				
		Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
34. Supplemental oxygen could be trialed to treat new focal neurological deficits postoperatively, even in the absence of hypoxemia	84% agreement	16	68	16	0	0
35. An IV fluid bolus should be administered to patients with a new focal neurological deficit following indirect revascularization surgery	100% agreement	33	67	0	0	0
36. An IV fluid bolus should be the first Intervention for patients with a new focal neurological deficit following indirect revascularization surgery	80% agreement	23	57	13	7	0
De-escalation of care						
37. Patients should be observed in an intensive care setting for at least 24 h following indirect revascularization surgery	90% agreement	63	27	3	7	0
38. Before transitioning out of the intensive care setting following indirect revascularization surgery, the patient should be meeting his or her blood pressure goals without vasopressor	93% agreement	53	40	3	0	3
39. Before being discharged following indirect revascularization surgery, patients should be observed in the hospital for a minimum of 24 h (inclusive of time in the ICU)	100% agreement	63	37	0	0	0

ICU intensive care unit, *IV* intravenous

Some statements that reached consensus were eliminated from the final statement because they were included in other statements and therefore redundant. For example, when two hierarchical statements (such as neuro checks should be monitored hourly for at least 6 h after surgery and neuro checks should be monitored hourly for at least 12 h after surgery) both reached consensus, the less stringent statement (in this case, the 6 h statement) was removed because it is included within the more stringent statement. Other statements deemed inappropriate due to answers to preceding questions were also removed. For example, there was no consensus about the need for central venous access, so three subsequent statements regarding duration of central venous access continuation were removed

[a]Assuming the line is functioning appropriately and not causing excessive discomfort or agitation