

# Posterior Circulation Ischemia or Occlusion in Five Adults With Failing Fontan Circulation

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**Background.** Palliative procedures performed before the Fontan procedure may require ligation of the subclavian arteries, thereby affecting flow to the vertebral arteries. In adults with functionally univentricular heart disease, the implications of altered brainstem vascular anatomy for perioperative management of failing Fontan circulation are not known.

**Methods.** We identified abnormal posterior circulation anatomy in an adult patient with failing Fontan circulation who experienced a brainstem stroke after Fontan conversion. We then changed our clinical practice to include detailed preoperative neurologic evaluation of adults with univentricular heart disease and failing Fontan circulation. Here, we report the clinical and neuroimaging findings in 5 consecutive patients before and after this change in practice.

**Results.** Five patients ages 28 to 42 years had Fontan procedures performed in childhood, and underwent either Fontan conversion or cardiac transplantation. Patient 1 experienced an episode of decreased cerebral perfusion pressure on postoperative day 3, and experienced an

ischemic brainstem stroke causing transient locked-in syndrome. A change in practice was made, and patients 2, 3, and 4 were evaluated preoperatively by the neurocritical care service. These patients then had higher target blood pressures perioperatively and no neurologic injury. Patient 5 was evaluated for symptoms consistent with subclavian steal. Neuroimaging in 3 patients was abnormal, with atrophic vertebral arteries, an occluded vertebral artery, and retrograde perfusion of a vertebral artery.

**Conclusions.** In adults with failing Fontan circulation there is a potential for neurologic complications as a result of venous congestion with elevated central venous pressures, and aberrant posterior circulation. The patient's history and brain imaging may be used to identify at-risk patients and to tailor perioperative management during Fontan conversion or heart transplantation to mitigate the risk for brainstem ischemia.

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Approximately 1 in 100 children are born in the United States each year with congenital heart disease (CHD) [1], including 0.5 to 5 per 10,000 live births with functionally univentricular heart disease (UVH) [2]. The Fontan procedure [3] is the most common procedure performed for CHD after the age of 2 years [4].

Improvements in perioperative management and performance of the Fontan procedure at a younger age have reduced operative mortality to less than 5%, and have led to a 20-year survival rate of 85% [5]. Adult survivors may develop medical complications including congestive hepatopathy, restrictive lung disease, renal dysfunction, and protein-losing enteropathy [6, 7]. The diagnosis, cause, and impact of these complications on long-term

survival have been described [6, 8]. Selection criteria for Fontan conversion, Fontan conversion with arrhythmia surgery, or cardiac transplantation have been identified [9–11]. Whether alteration in cerebrovascular anatomy after palliative operations affects long-term outcome after the Fontan procedure is not known.

The risk for neurologic complications after surgery for CHD has been well documented, especially in single-ventricle palliation. Specific neurologic complications after the Fontan procedure have also been described [12, 13]. In contrast, there is little published experience with the perioperative management of patients with UVH who undergo surgery in adulthood with regard to neurologic risk factors and neuroprotective strategies.

We identified abnormal posterior circulation anatomy in an adult patient with failing Fontan circulation who experienced a brainstem stroke on postoperative day 3 after Fontan conversion. We then changed our clinical practice to include detailed preoperative neurologic

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evaluation of adults with UVH and failing Fontan circulation. We report the clinical and neuroimaging findings in 5 such consecutive patients from 2013 to 2014.

## Patients and Methods

This retrospective study was approved by the institutional review board at the Ann & Robert H. Lurie Children's Hospital of Chicago. For each case, we reviewed the surgical history, clinical course, and results of brain imaging (Table 1). We also reviewed the database of patients with Fontan conversions maintained in the Department of Cardiovascular Thoracic Surgery at Lurie Children's Hospital for occurrence of strokes in previous patients since 1990.

Patient 1 was a 34-year-old man with CHD (left dominant atrioventricular canal) and UVH, who had undergone six palliative shunts before construction of a modified Fontan atrio-pulmonary connection at age 8 (Table 1). Systemic complications of his CHD included fibrotic liver disease. He had no neurologic deficits and worked full-time as a management consultant. He underwent Fontan conversion and maze procedure owing to recurrent atrial fibrillation and progressive exercise intolerance (Fig 1A). On postoperative day 3 while preparing for extubation, he became uncomfortable with rising blood pressure (Fig 1B), and was given benzodiazepines for presumed anxiety. Within 60 minutes he was able to move only his fingers and toes, and a short time later he became unresponsive. Repeat neurologic examination 90 minutes after symptom onset showed the ability to follow commands, minimal lateral eye movement, ptosis, and quadriplegia.

The preservation of consciousness with paralysis of all movement except for lateral gaze indicated injury to both corticospinal and corticobulbar tracts and the abducens nerves, consistent with a locked-in syndrome produced by injury in the ventral pons with preservation of function of the reticular activating system [14].

Brain imaging with magnetic resonance imaging could not be obtained because of the presence of a pacemaker system. Head computed tomography showed an area of encephalomalacia in the left cerebellar hemisphere consistent with an earlier posterior circulation stroke, but no evidence of acute ischemia (Fig 1C). Computed tomography angiogram was notable for patent anterior circulation with extremely diminutive posterior circulation and nonvisualized distal vertebral arteries (Figs 1D, 1E). Review of the patient's vital signs showed a central venous pressure (CVP) of 25 to 30 mm Hg and mean arterial pressures (MAPs) of 90 to 95 mm Hg, both rising when the patient became agitated. When the patient showed clinical signs of brainstem ischemia (arrow, Fig 1B), the CVP remained above 30 mm Hg, but the MAP decreased to the 70s. The patient was treated for presumed posterior circulation ischemia with augmentation of blood pressure and reduction in CVP to improve cerebral perfusion pressure. He recovered brainstem and motor function during the next 3 days. He died 4 months later of hepatorenal syndrome.

Table 1. Medical History, Systemic Complications, and Imaging Findings

| Case No. | Age at Fontan (y) | Surgeries Before Fontan Revision  | Age at Revision (y) | Cardiac Lesion                              | Systemic Complications  | Imaging   | Neurologic History                     |
|----------|-------------------|---|---------------------|---|---|---|--|
| 1        | 9                 | Right BT, Waterston; left BT; modified left BT; right central, unidirectional Glenn; Fontan                                   | 34                  | Unbalanced left dominant AV canal           | Stage 3 hepatic fibrosis, varicose veins                                  | Atrophic vertebral arteries with nonvisualized distal segments  | None                                   |
| 2        | 8                 | Cooley; direct central, unidirectional Glenn  | 35                  | DORV; VSD with straddling mitral valve; HLH | Stage 2-3 hepatic fibrosis; mild restrictive lung disease; hypothyroidism | N/A   | Migraine; restless legs                |
| 3        | 10                | Waterston   | 39                  | Tricuspid atresia                           | Restrictive lung disease; liver nodule; cirrhosis; splenomegaly           | Normal variant; absence of right A1 segment and fetal supply of the right PCA   | Chronic headache; left Erb's palsy     |
| 4        | 12                | Left BT, Waterston  | 42                  | Tricuspid atresia                           | Mild steatosis; minimal hepatic fibrosis; hypothyroidism                  | Left vertebral artery occlusion; functionally absent right PCOM   | Migraine                               |
| 5        | 2                 | Left BT, modified; revision left BT; right BT, modified; Fontan conversion to cavopulmonary lateral tunnel fenestrated Fontan | 24                  | TGA; pulmonary atresia                      | Hypothyroidism  | Left vertebral artery with retrograde flow through the circle of Willis secondary to absence of connection between left subclavian artery and aorta | Dizziness; headache; left arm weakness |

AV = atrioventricular; BT = Blalock-Taussig; DORV = double-outlet right ventricle; HLH = hypoplastic left heart; HLH = hypoplastic left heart; N/A = not available; PCA = posterior cerebral artery; PCOM = posterior communicating artery; TGA = transposition of the great arteries; VSD = ventricular septal defect.

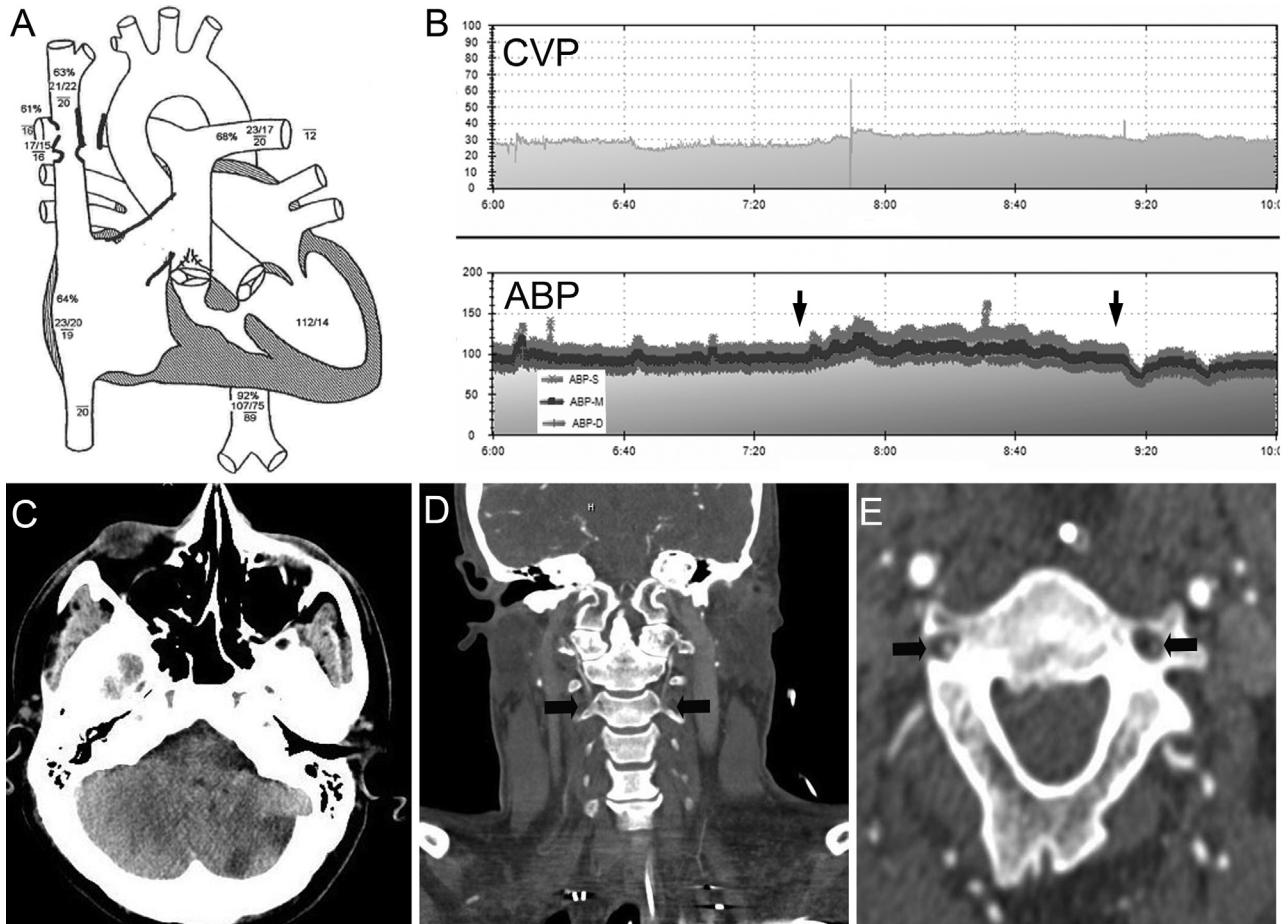


Fig 1. Imaging and physiologic recording for patient 1. (A) Anatomy of patient 1 showing Fontan palliation and relevant hemodynamic measurements from the preoperative catheterization. Of note are the elevated central venous pressures with mean values of 19 to 20 mm Hg. (B) Continuous recording of central venous pressure (CVP; upper panel) and arterial blood pressure (ABP; lower panel). Arrows show onset of symptoms of discomfort and agitation (first arrow) and quadriplegia (second arrow). Note the sustained elevation in central venous pressure and reduction in arterial blood pressure with the loss of motor function. (C) Axial noncontrast head computed tomography showing encephalomalacia in the left cerebellar hemisphere. (D) Coronal computed tomography two-dimensional angiogram showing the first visualization of the vertebral arteries (arrows) at approximately C5 (E).

After the experience with patient 1, a change in practice was made for adult patients with failing Fontan circulation to include preoperative neurologic evaluation. Neuroimaging was performed depending on the patient's reported neurologic symptoms and findings on a detailed neurologic examination. Patients 2, 3, and 4 were evaluated preoperatively by the neurocritical care service; details of their medical histories and imaging findings are in [Table 1](#). Patient 2 was a 35-year-old woman with UVH and double-outlet right ventricle, who underwent three palliative shunts (at 0.2, 2.9, and 6.7 years) before having an atrio-pulmonary Fontan connection performed at 8 years. She was pacemaker-dependent, and was admitted for management of heart failure. Her neurologic history was significant for migraine with aura since 15 years, obstructive and central sleep apnea, and recent onset of restless leg syndrome. Her neurologic examination was normal. No neuroimaging was obtained based on the normal neurologic examination and the absence of symptoms suggesting previous cerebral ischemic insult.

Patient 3 was a 39-year-old man with pulmonary atresia who underwent a palliative shunt in the neonatal period followed by an atrio-pulmonary Fontan at age 10. He underwent preoperative neurologic evaluation before Fontan conversion and maze procedure. Other medical issues include restrictive lung disease and cirrhosis. His neurologic history was notable for chronic headache and a remote history of left arm weakness related to Erb's palsy owing to perinatal brachial plexus injury. His neurologic examination showed mild left upper extremity weakness and subtle atrophy of the left arm. He also had a left Babinski reflex, suggesting a prior right subcortical injury. Brain imaging revealed normal anatomic vessel variants with a fetal type supply of the right posterior cerebral artery in which this vessel arose not from the basilar artery but from the internal carotid artery.

Patient 4 was a 42-year-old woman with a history of tricuspid atresia who underwent two palliative shunts at 0.5 and 1.3 years before having an atrio-pulmonary Fontan connection at 12 years. She underwent neurologic



evaluation before undergoing a Fontan conversion. Systemic complications of her cardiac disease included congestive hepatopathy and pulmonary embolism requiring anticoagulation. She had a history of migraines with aura and frequent presyncopal symptoms on standing. Her neurologic examination was also normal. Magnetic resonance imaging and computed tomography angiogram of the head and neck were abnormal with absence of the left vertebral artery (Figs 2A, 2B).

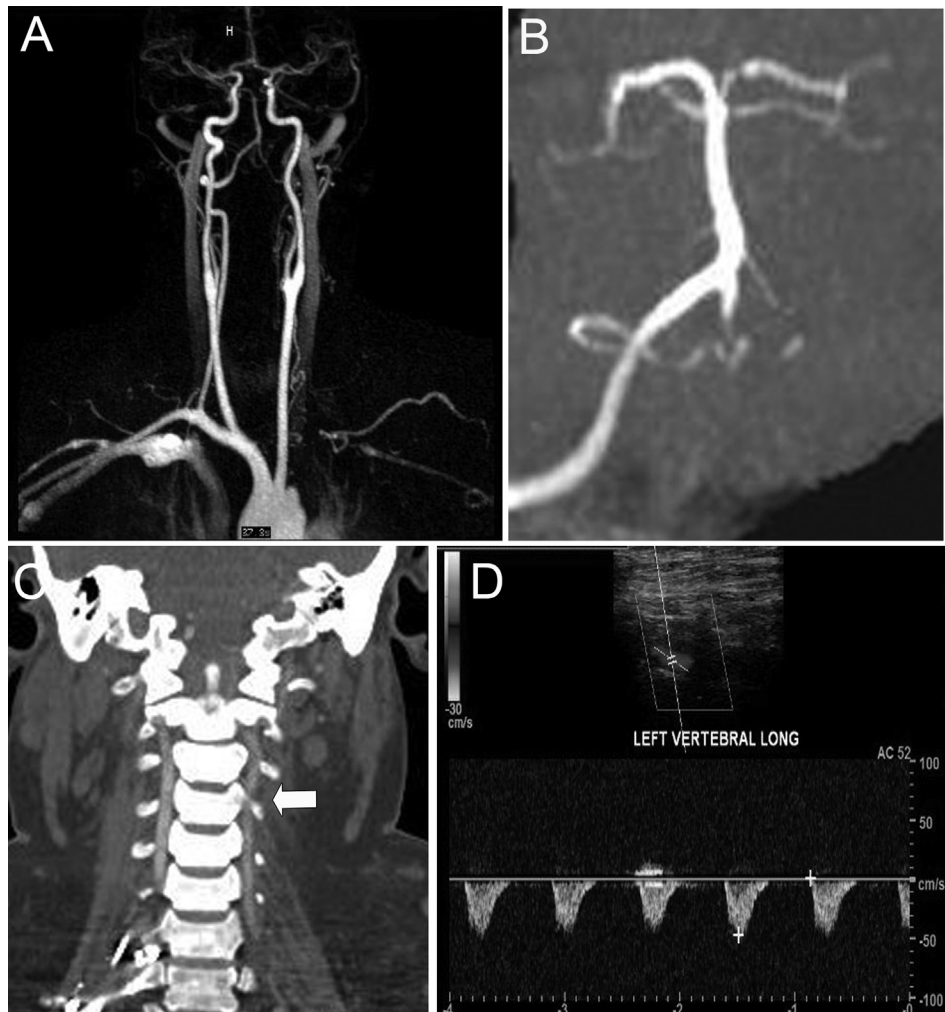
Patient 5 was a 28-year-old woman with transposition of the great arteries and pulmonary valve atresia with UVH physiology. She had multiple surgeries (three palliative shunts, Fontan surgery at 2.4 years, and revisions at 6.2 and 6.4 years) before homograft aortic root replacement for progressive aortic insufficiency at 13.5 years. At 24 years she underwent a Fontan conversion, aortic root replacement, maze procedure, and pacemaker implantation. She had recurrent episodes of headache, dizziness, left neck pain, and left arm numbness precipitated by exercise. Brain computed tomography angiography revealed the absence of a connection between the aorta and left subclavian artery, presumably

resulting from the palliative shunt. The left vertebral artery was small (Fig 2C) with delayed and retrograde flow through the circle of Willis demonstrated by transcranial Doppler (Fig 2D). The symptoms of vertebrobasilar insufficiency (dizziness and headache) and left arm weakness were consistent with a subclavian steal physiology.

## Results

The intraoperative management of patients 2 through 4 was not altered from our standard practice (patient 5 had undergone Fontan conversion 4 years before this reported admission). Mannitol (3 mL/kg with a maximum of 50 mL) is our standard in the priming solution for cardiopulmonary bypass. The lowest temperature during bypass for these patients was 32.0°C. During bypass, MAP was maintained at 60 mm Hg and was adjusted with low doses of phenylephrine if needed. Central venous pressure is typically low (<5 mm Hg) and was not manipulated. The target activated clotting time is more than 480 seconds, and the lowest hematocrit for these

Fig 2. Cerebrovascular imaging for patients 4 and 5. (A) Magnetic resonance angiogram of the head and neck of patient 4 showing occlusion of the proximal left vertebral artery. (B) Computed tomography angiogram of patient 4 showing absence of the left vertebral artery. (C) Computed tomography angiogram of patient 5 showing a small, atrophic left vertebral artery compared with the right vertebral artery (arrows). (D) Transcranial Doppler study of the left vertebral artery in patient 5 showing retrograde flow.



patients ranged from 28 to 32 mg/dL. No anticoagulation was administered in the postoperative period.

While intubated, patients 2, 3, and 4 were managed perioperatively by maintaining a cerebral perfusion pressure of greater than 50 mm Hg, assuming normal intracranial pressure. These patients tolerated their procedures well without neurologic sequelae. Patient 5 had undergone a Fontan conversion at 24 years, 4 years before the admission with symptoms of subclavian steal, and was managed with limited aerobic exercise to avoid steal of vertebrobasilar artery flow to the left subclavian artery.

## Comment

This small case series demonstrates abnormal posterior circulation anatomy in 3 of 5 adult patients who had undergone the Fontan procedure. These cases highlight the need for greater understanding of the potential neurologic impact of altered posterior cerebral circulation blood flow caused by previous palliative procedures and the implications of this vascular anatomy for the postoperative management of these patients in the intensive care unit. The Fontan procedure is performed in children with complex CHD with only one functioning ventricle. The procedure is performed after other cardiac operations that may have required ligation of the subclavian arteries in earlier generations of this palliation, potentially altering flow to the vertebral arteries [15]. The implications of altered brainstem vascular anatomy for perioperative management of adults with failing Fontan circulation are not known. We hypothesize that the combination of venous congestion with chronic elevation in CVP and abnormal posterior circulation anatomy may increase the risk for brainstem ischemia. We suggest that this risk should be considered during the preoperative evaluation and perioperative management of adults with failing Fontan circulation.

Patients with Fontan physiology have chronic systemic venous congestion with elevated CVP [6, 16]. While intubated, these patients may have further increases in intrathoracic pressures caused by the positive end-expiratory pressure supplied by conventional mechanical ventilation. During initial surgical palliations, connection of the innominate or subclavian arteries to the pulmonary arteries may alter the posterior circulation anatomy. Indeed, cerebrovascular imaging in 3 of our 5 patients demonstrated atrophic vertebral arteries in patient 1, an occluded left vertebral artery in patient 4, and retrograde flow in the left vertebral artery in patient 5. Thus, a small decrease in MAP when combined with a high CVP may result in a fall in cerebral perfusion pressure, preferentially affecting the posterior circulation as we hypothesize occurred in patient 1.

The frequency of this abnormality in patients with UVH is not clear, but the clinical impact of brainstem ischemia is significant. The outcome from posterior circulation strokes in adults is poor [14]. Since 1990 at our center, 139 Fontan conversions have been performed. Of these patients, 107 (77%) were older than 18 years at the time of conversion surgery. Sixteen patients (12%)

self-reported a history of stroke symptoms before surgery (unpublished data). In our local database of patients with Fontan conversions, no early postoperative neurologic complications were recorded. These data are limited by the accuracy of self-reporting and by the potential for clinically silent cerebral ischemia. Indeed, patient 1 had an old clinically silent cerebellar stroke, suggesting that the incidence of strokes in these patients may be underestimated. Patients 2 and 3 had no symptoms referable to the vertebrobasilar insufficiency, and patient 3 had a normal variant of posterior cerebral artery. Both these patients had central shunts. Thus, the type of shunt and the ligation of the vertebral or subclavian artery along with other lifestyle risk factors for vascular disease may contribute to differences in individual risk for chronic neurologic complications. Understanding the burden of neurologic morbidity in these patients will require further study with prospective detailed neurologic evaluation and neuroimaging, following the clinical practice we instituted after patient 1.

Compromise of posterior circulation perfusion has not previously been identified as a potential long-term sequela of the palliative aorto-pulmonary shunt procedure. Anesthesia guidelines for patients undergoing Fontan conversion address potential complications from anesthetic agents on a patient's underlying cardiac dysfunction, protein-losing enteropathy, arrhythmias, and bleeding diathesis, but do not address intraoperative or postoperative risk for neurologic injury [16]. A previous history of stroke or thromboembolism is known to be a risk factor for increased perioperative morbidity and mortality, but there are no specific recommendations to address this increased risk [16]. Guidelines for cardiac intensive care unit management of these patients address management of heart failure and arrhythmia [17], but there is no specific mention of management of cerebral perfusion pressure. Previous publications addressing stroke in Fontan patients mention risk for embolic stroke, such as right-to-left shunt and hypercoagulability [13, 18, 19].

Our patients also exhibited many of the chronic medical complications of CHD, including restrictive lung disease, hepatic fibrosis, and renal impairment, as well as several chronic neurologic symptoms including migraines and sleep apnea [20, 21]. Migraines are common in both cyanotic and noncyanotic congenital cardiac lesions, but there are no specific guidelines for their management in adults with CHD [22–26]. The history of headaches (patients 2, 3, and 4) and restless legs syndrome (patient 2) may be unrelated to vertebrobasilar insufficiency, as restless legs syndrome is not a typical manifestation of posterior circulation ischemia and headaches are clearly common in the general population.

We suggest that specific features of the history of patients with functionally UVH physiology may be used to tailor perioperative management during Fontan conversion or heart transplantation to mitigate the risk for brainstem ischemia. During the preoperative evaluation, patients who have undergone prior aorto-pulmonary shunt staging or who report symptoms suspicious for vertebrobasilar ischemia including diplopia, vertigo,

ataxia, recurrent headaches [26], or any transient neurologic deficits should undergo neurologic evaluation including computed tomography or magnetic resonance imaging angiography of the head and neck. If abnormal posterior circulation is present, or if the neurologic symptoms are clearly referable to vertebrobasilar insufficiency, the perioperative management of these patients should include predefined blood pressure goals to maintain stable cerebral perfusion pressure during periods when either CVP rises or MAP is decreasing. The specific perfusion pressure goal for each patient may vary depending on their blood pressure before the operation. Among adults with UVH, the percentage of patients affected may be small but the consequences of brainstem ischemia are grave, and focused history and imaging may help identify preventable complications of this operation.

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