

REVIEW ARTICLE

Pediatrics

Pediatric stroke in the emergency department

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Abstract

Strokes are more commonly seen in adults but also occur in the pediatric population. Similar to adult strokes, pediatric strokes are considered medical emergencies and require prompt diagnosis and treatment to maximize favorable outcomes. Unfortunately, the diagnosis of stroke in children is often delayed, commonly because of parental delay or failure to consider stroke in the differential diagnosis. Children, especially young children, often present differently than adults. Much of the treatment for pediatric strokes has been adapted from adult guidelines but the optimal treatment has not been clearly defined. In this article, we review pediatric strokes and the most recent recommendations for treatment.

KEYWORDS

emergencies, pediatrics, stroke

1 | INTRODUCTION

Although commonly thought of as an adult disease, strokes also occur in the pediatric population and result in significant morbidity and mortality. The sequelae last for decades and cause significant burden on the patient and family. In this article, we review pediatric strokes including their etiology, diagnosis, and management. A literature search was performed using the PubMed database and the search terms: *pediatric stroke*, *childhood stroke*, *pediatric ischemic stroke*, *pediatric hemorrhagic stroke*, *perinatal stroke*, and *cerebral sinus venous thrombosis*. Results were limited to studies involving pediatric patients (aged 0–18 years) and studies in English. References within the articles were reviewed for possible inclusion. A total of 58 articles were included.

Pediatric strokes can be divided into ischemic strokes, which include arterial ischemic strokes (AIS) and cerebral sinus venous thrombosis (CSVT), and hemorrhagic strokes. Strokes can also be divided into perinatal strokes, which occur between 20 weeks of fetal life and the 28th postnatal day, and childhood strokes, which occur between 29 days and 18 years of age. Perinatal strokes are not rare and are significantly more common than strokes in older children.¹ The majority

of perinatal strokes are AIS although CSVT and hemorrhagic strokes can occur. Agrawal et al identified a prevalence of perinatal AIS of 29 per 100,000 live births. This increased to 37 per 100,000 live births when perinatal hemorrhagic strokes were included.²

Fullerton et al identified an incidence of first-time childhood stroke of 2.3 per 100,000 children (1.2 with AIS and 1.1 with hemorrhagic stroke). When further divided into age subgroups, infants (>30 days but <1 year of age) had the highest annual stroke rates including AIS and hemorrhagic strokes. Late teens (15 to 19 years of age) had the second highest annual stroke rates. When hemorrhagic strokes were further divided into intracerebral hemorrhage and subarachnoid hemorrhage, late teens actually had the highest rate of subarachnoid hemorrhage. Boys had a higher risk of strokes than girls. Black children had greater than twice the risk of stroke compared to white children. After patients with sickle cell disease were excluded, black children still had a 61% increased risk. Asian children had a similar risk to white children and Hispanic children had a lower risk.³

There is frequently a delay in the diagnosis of stroke in pediatric patients with multiple studies showing a median time from onset of symptoms to diagnosis of AIS of >20 hours.^{4–6} A neurologic deficit in

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young children may be subtle and parents may delay seeking care. Additionally, stroke is often misdiagnosed or not initially considered in the differential diagnosis. Rafay et al found that stroke was suspected by the initial physician in only 38% of patients who were ultimately diagnosed with AIS.⁴ Strokes in children, as in adults, are a medical emergency and should be treated rapidly to maximize favorable outcomes. There is a paucity of data regarding morbidity and mortality because of delays in treating strokes in children. However, the adult literature has shown that earlier thrombolytic treatment for AIS is associated with decreased in-hospital mortality as well as decreased disability.^{7,8} In an effort to improve the treatment of pediatric strokes, pediatric centers have emulated adult stroke centers and have developed acute stroke protocols.^{9,10} In one study, the development of a stroke alert protocol decreased the median time to diagnosis by over one half for children who presented to the emergency department with acute neurologic deficits.⁹

2 | PERINATAL STROKES

We discuss perinatal strokes separately because they often present differently than childhood strokes and are poorly understood. Additionally, most literature examines neonates separately. Patients who present in the first 28 days of life are described as having a neonatal stroke. Patients can also present later with symptoms such as pathological early handedness, subtle hemiparesis, or seizures and neuroimaging suggestive of a remote stroke. These patients are described as having a presumed perinatal stroke.¹¹ The etiology of perinatal strokes is likely multifactorial and related to the unique conditions of the peripartum period. DeVeber et al found that 56% of neonates with AIS presented with at least one risk factor including 34% with an acute illness, 23% with a prothrombotic disorder, and 17% with a cardiac disorder or cardiac surgery. Possible maternal risk factors included primiparity, maternal fever, gestational diabetes or hypertension, preeclampsia, and premature rupture of membranes. Eighty-eight percent of neonates with AIS presented with a seizure, including focal and generalized seizures. A significant number of neonates also presented with cardiorespiratory symptoms such as apnea and cyanosis as well as diffuse motor deficits. Only 1% of neonates experienced a recurrent stroke, which is much lower than for non-neonates.¹² Care is largely supportive but treatment with antiplatelet or anticoagulation therapy may be considered in patients with thrombophilia or complex congenital heart disease.¹³

3 | ETIOLOGY

Whereas the majority of adult strokes are due to atherosclerosis that develops as a result of hyperlipidemia, hypertension, diabetes mellitus, smoking, and obesity, strokes in pediatric patients have different etiologies and risk factors. In discussing these, we have divided strokes into AIS, CSVT, and hemorrhagic strokes with a focus on childhood strokes.

3.1 | Arterial ischemic stroke

There are multiple etiologies and risk factors associated with pediatric AIS as well as some overlap between risk factors. The International Pediatric Stroke Study examined a large cohort of patients aged 1 month to 18 years diagnosed with AIS and identified risk factors (Table 1). The most common risk factors were arteriopathies, cardiac disorders, and infections.¹⁴

3.1.1 | Arteriopathies

Arteriopathies account for the majority of childhood AIS. Patients with an arteriopathy have a 5-fold increased risk of recurrent stroke compared to patients with an idiopathic AIS.¹⁵ Arteriopathies include focal cerebral arteriopathies, arterial dissection, moyamoya, and vasculitides.

Focal cerebral arteriopathies (FCA) are unifocal and unilateral irregularities of the large intracranial arteries. FCA is further divided into FCA-d, or dissection type, which refers to intracranial arterial dissection, and FCA-i, or inflammation type, which refers to FCA that is presumed to be inflammatory.¹⁶ In cases of FCA-i, it is thought that an infectious process leads to local vascular inflammation, which then leads to thrombus formation and stroke. Recent upper respiratory infection is a positive predictor of having an FCA-i, suggesting that infection could promote a proinflammatory or procoagulant effect.^{17,18} Infection with varicella zoster virus, in particular, has been labeled postvaricella arteriopathy and has been shown to increase the risk of stroke for 6 months following infection.¹⁹

Extracranial arterial dissection is another important cause of AIS. Over half of patients with arterial dissection experience concurrent or recent trauma but a significant percentage occur spontaneously. Connective tissue and genetic disorders can also predispose to dissection.²⁰

Moyamoya ("puff of smoke" in Japanese) disease is caused by stenosis of the internal carotid arteries at the base of the brain along with the development of collateral vessels, which give the appearance of a puff of smoke. Lee et al found that 90% of patients with moyamoya disease presented with AIS but 7.5% presented with transient ischemic attacks and 2.5% presented with hemorrhagic strokes. Recurrent strokes occurred frequently with 20% of patients experiencing another stroke at 13 months. Moyamoya can be associated with other conditions such as sickle cell disease, Down syndrome, and neurofibromatosis.²¹

3.1.2 | Cardiac disorders

Cardiac disorders are another significant cause of pediatric AIS. The incidence of pediatric AIS is significantly increased in patients with congenital and acquired cardiac disorders and is typically cardioembolic. Patients with single ventricle cardiac disease have the highest incidence. Patients with AIS were also found to have atrioventricular septal

TABLE 1 Risk factors associated with arterial ischemic strokes (some children had >1 risk factor)¹⁴

Arteriopathies (53%)	Focal cerebral arteriopathy Moyamoya Arterial dissection Vasculitis Sickle cell arteriopathy Post varicella arteriopathy
Cardiac (31%)	Congenital heart disease Acquired heart disease Post-cardiac surgery (<72 hours) Previous cardiac surgery Isolated patent foramen ovale Cardiac catheterization Extracorporeal membrane oxygenation Left ventricular assist device Arrhythmia
Infection (24%)	Includes infections listed in other categories
Acute head and neck disorders (23%)	Head/neck trauma Pharyngitis Meningitis Recent intracranial surgery Otitis media Sinusitis Mastoiditis
Acute systemic conditions (22%)	Fever >48 hours Sepsis Shock Dehydration Acidosis Anoxia Viral gastroenteritis
Chronic systemic conditions (19%)	Sickle cell disease Indwelling catheter Trisomy 21 Hematological malignancy Iron deficiency Oral contraceptive pill Connective tissue disease Solid extracranial tumors L-asparaginase
Prothrombotic states (13%)	Methyl tetrahydrofolate reductase (MTHFR) Elevated lipoprotein A Acquired thrombophilia Factor V Leiden Protein S deficiency Prothrombin 20210A Protein C deficiency Antithrombin III deficiency Hyperhomocysteinemia
Chronic head and neck disorders (10%)	Migraine Brain tumors Ventriculoperitoneal shunts Cerebral aneurysm MELAS (mitochondrial encephalopathy with lactic acidosis and strokelike episodes) Intracranial arteriovenous malformations PHACES syndrome (malformations of the posterior fossa, facial hemangioma, arterial cerebrovascular anomalies, cardiovascular anomalies, abnormalities of the eye and sternum)

defects, Ebstein anomaly, arrhythmias, and cardiomyopathy secondary to myocarditis.²² Additionally, patients who undergo cardiac catheterization or cardiac surgery are at an increased risk.^{23,24} Patients who require ventricular assist devices are also at an increased risk of AIS although hemorrhagic strokes can occur.^{25,26}

3.1.3 | Sickle cell disease

One disease that deserves special attention is sickle cell disease. Patients with sickle cell disease are at risk for developing a vasculopathy, typically of the internal carotid and middle cerebral arteries, which places them at an increased risk for stroke, especially AIS. The development of screening with transcranial Doppler (TCD) to identify elevated cerebral blood flow has led to chronic red blood cell transfusion therapy and a significantly decreased risk of stroke. In a study evaluating the incidence of stroke since instituting TCD screening and chronic transfusion therapy, 2.1% of patients still had AIS. A significant number of these patients had abnormal TCD velocities and the majority had a lack of appropriate TCD screening or insufficient chronic transfusion therapy.²⁷

3.2 | Cerebral sinus venous thrombosis

CSVT is a rare but important cause of pediatric stroke. Thrombosis leads to elevated venous pressure, which can lead to secondary ischemia and infarction. Hemorrhagic transformation can also occur. In one study, the incidence of CSVT was 0.67 cases per 100,000 pediatric patients with 43% neonates and 54% < 1 year of age. The majority of patients had a risk factor but they were different depending on the age. For neonates, the majority had a perinatal complication such as hypoxic encephalopathy. In preschool children, head and neck infections such as otitis media, sinusitis, and mastoiditis were significant risk factors. Dehydration was an important risk factor in all ages. Prothrombotic states have also been associated with CSVT.²⁸ Lastly, CSVT can occur following blunt head trauma, especially with a skull fracture near a dural sinus.^{29,30}

3.3 | Hemorrhagic stroke

Hemorrhagic strokes account for nearly half of all pediatric strokes and result in significant mortality and morbidity. Al-Jarallah et al looked at children and adolescents with non-traumatic intracranial hemorrhage and identified a death rate of 8.8% although many studies show a much higher death rate.³¹ At least 50% of children develop a significant disability.^{31,32} Al-Jarallah et al identified the most common risk factors (Table 2). The majority of patients had vascular anomalies followed by hematologic disorders and coagulopathies. Some patients had multiple risk factors. In addition to the risk factors they identified, patients who are placed on extracorporeal membrane oxygenation (ECMO) are also at an increased risk of hemorrhagic stroke, especially neonates

TABLE 2 Risk factors for hemorrhagic strokes (some children had >1 risk factor)³¹

Vascular anomalies (42.6%)	Arteriovenous malformation/fistula Aneurysms Cavernous malformation
Hematologic disorders (17.6%)	Thrombocytopenia: - Secondary to chemotherapy - Isoimmune thrombocytopenia - Thrombocytopenia-absent radius (TAR) syndrome - Sickle cell disease
Coagulopathies (14.7%)	Hemophilia A Liver failure Warfarin therapy Factor XIII deficiency Vitamin K deficiency Protein C and S deficiencies (likely hemorrhagic transformation of AIS)
Brain tumor (13.2%)	Bleeding into region of brain tumor
Unknown (10.3%)	
Hemorrhagic transformation of arterial/venous infarction (8.8%)	

and patients who are placed on ECMO for cardiac indications. AIS also occurs in a significant portion of these patients.³³

4 | PRESENTATION

Patients present differently depending on their age and the type of stroke. Children with AIS often present with focal weakness like adults. However, children < 6 years of age, and especially younger than 1 year of age, are more likely to present with altered mental status and seizures.^{34,35} Mallick et al looked at AIS patients aged 29 days to 16 years and found that 85% presented with focal features with 72% presenting with hemiparesis. A significant amount presented with facial weakness and speech disturbance. In this same study, 61% of patients presented with diffuse features such as decreased level of consciousness, headache, and vomiting. Twenty-nine percent of patients presented with a seizure with 75% of these patients being younger than 1 year of age. Diffuse features or seizures rarely occurred in isolation and usually occurred along with a focal feature.³⁴

Patients with CSVT can present with subtle signs and symptoms. Seizures and decreased level of consciousness are a common presentation in all ages. Neonates, who comprise a large percentage of patients, often present with jittery movements, irritability, and hypotonia. Non-neonates often present with headache or focal neurologic signs such as hemiparesis, visual impairment, ataxia, speech impairment, or cranial nerve palsies.^{28,36}

Children with hemorrhagic stroke often present similar to adults with over half presenting with headache or vomiting. A significant number also present with seizures and altered mental status as well as focal neurologic deficits such as hemiparesis or aphasia.^{31,32,37}

The National Institutes of Health (NIH) stroke scale for adults has been modified to create the Pediatric NIH stroke scale, or PedNIHSS (Table 3). It contains the same elements as the adult NIH stroke scale but is modified to account for differences in age and development. Like the adult NIH stroke scale, the total score ranges from 0 (least severe) to 42 (most severe). The PedNIHSS can be used in pediatric patients ≥ 2 years of age with AIS but has not been validated for hemorrhagic strokes. It can be used to quantify the severity of pediatric AIS and can be trended to monitor recovery. The PedNIHSS has been shown to have excellent interrater reliability as well as validity and reliability when scored retrospectively. However, in these studies, patients were scored by child neurologists. It is unclear if this would also apply to non-neurologists.^{38,39}

5 | DIFFERENTIAL DIAGNOSIS

The differential diagnosis for strokes in the pediatric population is broad. Mackay et al identified the following most common “mimic” diagnoses in patients 1 month to 18 years (in order of most to least common): migraines, seizures, Bell's palsy, conversion disorder, and syncope. Several variables were found to be significantly associated with stroke mimics: the absence of focal neurological signs on examination and the presence of: pain or stiffness, lethargy, gait disturbance, fever, involuntary movements, nausea, and irritability. However, there were also stroke patients who presented with these symptoms.⁴⁰ Additionally, in a study of patients suspected of having a stroke who were diagnosed with a stroke mimic, 63% had a non-benign diagnosis including reversible posterior leukoencephalopathy syndrome, neonatal seizures, vascular anomalies, inflammatory disease, intracranial infection, epilepsy, metabolic stroke, tumor, drug toxicity, and idiopathic intracranial hypertension. This suggests that most patients with stroke symptoms require a thorough evaluation including magnetic resonance imaging (MRI).⁴¹

Migraines are the most common stroke mimic. Mackay et al found that 28% of pediatric patients with stroke symptoms were diagnosed with migraines.⁴² In a study comparing pediatric AIS patients to migraine patients, children with migraines were significantly older than those with AIS with a median age of 13 years for migraine patients and 5 years for AIS patients. Sudden symptom onset was more frequent in AIS patients whereas symptoms occurred more gradually in migraine patients. Visual and sensory disturbances were more frequent in migraine patients as were vomiting and resolution of neurologic deficits before emergency department assessment.⁴³

6 | DIAGNOSTIC STUDIES

Urgent neuroimaging is essential for rapid diagnosis and timely intervention. MRI of the brain is the preferred initial study and could identify AIS, CSVT, or hemorrhagic strokes. Ideally, magnetic resonance angiography (MRA) of the head and neck should also be performed to evaluate for arteriopathy, thrombus, or arterial dissection, especially

TABLE 3 Pediatric NIH stroke scale³⁹

Examination	Score
1A. Level of consciousness (LOC)	0 = Alert; keenly responsive 1 = Not alert, but arousable by minor stimulation 2 = Not alert, requires repeated stimulation, or is obtunded and requires strong or painful stimulation to make movements (not stereotyped) 3 = Responds only with reflex motor or autonomic effects or totally unresponsive, flaccid, areflexic
1B. LOC Questions Q1 How old are you? Q2 Where is XX? (XX = caregiver's name)	0 = Answers both questions correctly 1 = Answers 1 question correctly 2 = Answers neither question correctly
1C. LOC Commands C1 Open and close your eyes. C2 Touch your nose.	0 = Performs both tasks correctly 1 = Performs 1 task correctly 2 = Performs neither task correctly
2. Best Gaze	0 = Normal 1 = Partial gaze palsy 2 = Forced deviation, or total gaze paresis not overcome by the oculocephalic maneuver.
3. Visual fields Children up to age 6 years: testing done with visual threat Children >6 years: testing done by confrontation using finger counting	0 = No visual loss 1 = Partial hemianopia 2 = Complete hemianopia 3 = Bilateral hemianopia including any cause of blindness
4. Facial palsy	0 = Normal symmetrical movement 1 = Minor paralysis (flattened nasolabial fold, asymmetry on smiling) 2 = Partial paralysis (total or near total paralysis of lower face) 3 = Complete paralysis of 1 or both sides (absence of facial movement in the upper and lower face)
5. Motor arm 5a left arm 5b right arm For children too immature to follow precise directions or uncooperative for any reason, power in each limb should be graded by observation of spontaneous or elicited movements according to the same grading scheme, excluding the time limits	0 = No drift 1 = Drift, limb holds 90 (or 45) degrees but drifts down before 10 seconds, does not hit bed or other support 2 = Some effort against gravity 3 = No effort against gravity, limb falls 4 = No movement 9 = Amputation, joint fusion
6. Motor leg 6a left leg 6b right leg	0 = No drift 1 = Drift, leg falls by the end of the 5 second period but does not hit bed 2 = Some effort against gravity 3 = No effort against gravity, leg falls to bed immediately 4 = No movement 9 = Amputation, joint fusion
7. Limb ataxia In children <5 years, substitute tasks on adult scale with reaching for a toy for the upper extremity and kicking a toy or examiner's hand for the lower extremity	0 = Absent or paralyzed or patient does not understand 1 = Present in 1 limb 2 = Present in 2 limbs
8. Sensory For children too young or otherwise uncooperative for reporting gradations of sensory loss, observe for any behavioral response to pin prick, and score it according to same scoring scheme as a "normal" response, "mildly diminished," or "severely diminished" response	0 = Normal; no sensory loss 1 = Mild to moderate sensory loss; patient feels pinprick is less sharp or is dull on the affected side; or there is a loss of superficial pain with pinprick but patient is aware he/she is being touched 2 = Severe to total sensory loss; patient is not aware of being touched in the face, arm, and leg
9. Best language For children 2–6 years or older children with premorbid language disability, item scored based on observations of language comprehension and speech during preceding examination	0 = No aphasia, normal 1 = Mild to moderate aphasia 2 = Severe aphasia 3 = Mute, global aphasia; no usable speech or auditory comprehension.
10. Dysarthria	0 = Normal 1 = Mild to moderate; patient slurs at least some words and, at worst, can be understood with some difficulty 2 = Severe; patient's speech is so slurred as to be unintelligible or is mute/anarthric 9 = Intubated or other physical barrier

(Continues)

TABLE 3 (Continued)

Examination	Score
11. Extinction and inattention	0 = No abnormality 1 = Visual, tactile, auditory, spatial, or personal inattention or extinction to bilateral simultaneous stimulation in 1 of the sensory modalities 2 = Profound hemi-inattention to more than 1 modality. Does not recognize own hand or orients to only 1 side of space

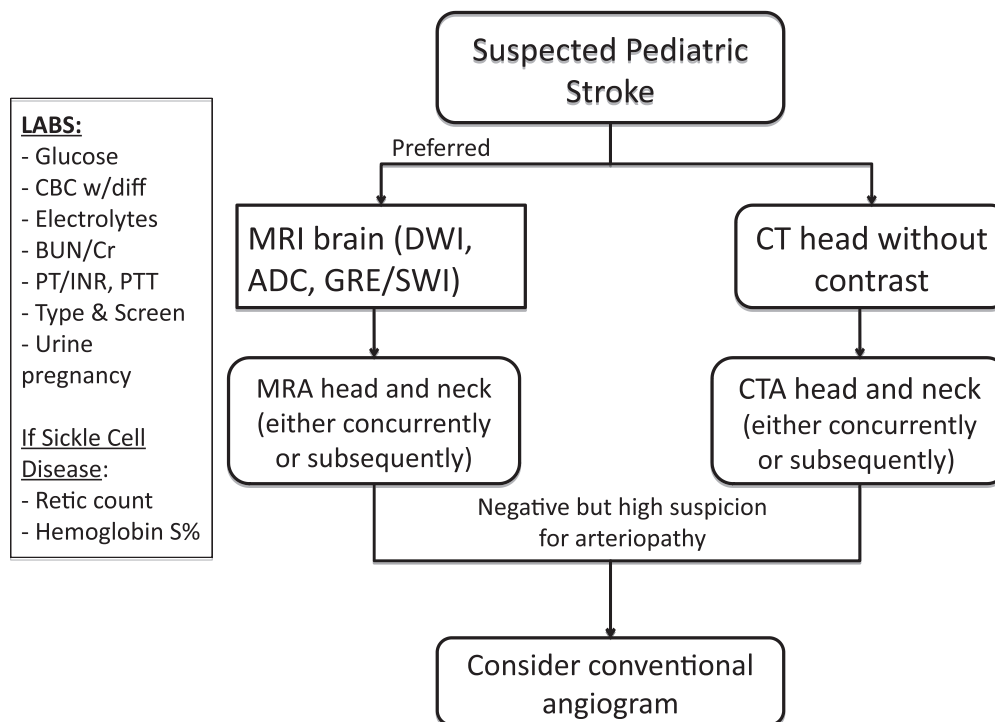


FIGURE 1 Imaging and labs for suspected pediatric stroke.^{44,46,47} Imaging adapted from the International Paediatric Stroke Study Neuroimaging Consortium.⁴⁴ MRI, magnetic resonance imaging; DWI, diffusion weighted imaging; ADC, apparent diffusion coefficient; GRE, gradient echo; SWI, susceptibility weighted imaging; CT, computed tomography; MRA, magnetic resonance angiography; CTA, computed tomography angiogram; CBC w/diff, complete blood count with differential; BUN, blood urea nitrogen; Cr, creatinine; PT/INR, prothrombin time/international normalized ratio; PTT, partial thromboplastin time; Retic, reticulocyte

if the administration of thrombolytics is being considered. Many centers have developed rapid or abbreviated brain MRI protocols, which can be completed in a shorter time than conventional MRIs. This allows for more rapid diagnosis and may allow for MRIs to be performed in pediatric patients who would otherwise require sedation. These protocols typically include diffusion-weighted imaging (DWI) and apparent diffusion coefficient (ADC) maps to diagnose ischemic stroke as well as gradient echo (GRE) sequences or susceptibility-weighted imaging (SWI) to detect hemorrhage.⁴⁴ The International Paediatric Stroke Study Neuroimaging Consortium devised an imaging protocol for children aged 29 days to 18 years with suspected stroke (Figure 1). Christy et al looked at children who were admitted with acute AIS. Children received either a computed tomography (CT) head, a full MRI, an abbreviated MRI consisting of T-2-weighted fast spin-echo images + DWI sequence, or a combination of CT and MRI. This was a small study

but the abbreviated MRI protocol was 100% sensitive for detecting AIS. The abbreviated MRI protocol did miss a small petechial hemorrhage on one patient. However, their abbreviated protocol did not include GRE or SWI sequences, which are more sensitive at detecting hemorrhage.⁴⁵

If there are contraindications to MRI, MRI is not readily available, or the patient is unstable or uncooperative, then non-contrast head CT should be performed along with CT angiogram (CTA) of the head and neck. If the CT studies are not diagnostic, an MRI would still need to be performed because of the poor sensitivity of CT for pediatric AIS. In one series, CT diagnosed AIS in only 53% of cases.⁴ If CTA or MRA are not diagnostic in a patient with a strong suspicion of arteriopathy, conventional catheter angiogram may be required.⁴⁴ In addition to imaging, standard laboratory studies are typically ordered (Figure 1).^{46,47} Other tests should be ordered based on the patient's presentation.

7 | TREATMENT

Initial treatment always consists of the ABCs (airway, breathing, and circulation). Patients should be made NPO (nothing by mouth). Two peripheral intravenous lines should be placed if possible. In cases of known or suspected ischemic stroke, the head of the bed should be kept flat. In cases of known or suspected hemorrhagic stroke, nausea, or vomiting, or other signs of increased intracranial pressure, the head of the bed should be elevated to 30 degrees and the head kept midline to encourage venous drainage.^{13,48}

7.1 | Arterial ischemic stroke

There are limited data on the effects of hypertension, fever, and glucose control in pediatric AIS patients but it is reasonable to follow the adult stroke guidelines. It is unclear whether hypertension after stroke leads to higher mortality or morbidity. In one study of pediatric patients with AIS, hypertension was associated with increased mortality and increased length of stay.⁴⁹ Rivkin et al recommend that patients' target systolic blood pressure be maintained between the 50th and 90th percentile for age. Significant hypertension may require treatment with labetalol or nicardipine to lower the blood pressure by 15%–25% over 24 hours or more quickly if thrombolytics will be given. If there is hypotension, administer normal saline boluses followed by pressors as needed. Patients ≥ 2 years of age should be given isotonic fluids (eg, 0.9% NaCl) at maintenance with normal saline boluses as needed to maintain normovolemia. No dextrose is needed unless the patient is hypoglycemic. Consider dextrose containing fluids (eg, D5 0.9% NaCl) for patients < 2 years of age. Maintain normothermia and treat fever with acetaminophen. Hypoxia and hypercarbia should be avoided. Lastly, seizures should be treated aggressively with anticonvulsants. Consider continuous electroencephalography if there is concern for persistent or subclinical seizure activity.^{13,48}

Recanalization therapies for pediatric AIS, including intravenous/intra-arterial tissue plasminogen activator (tPA) and endovascular thrombectomy are not well established. Treatment regimens with tPA have been adapted from adult practices. Recanalization carries the risk of hemorrhage, reperfusion injury, and complications from the catheter or device.¹³ There have been only small case series of pediatric stroke patients treated with tPA. The National Institute of Neurological Disorders and Stroke funded the Thrombolysis in Pediatric Stroke (TIPS) trial to determine the ideal dose and safety of intravenous tPA for pediatric patients with AIS. Unfortunately, the trial closed because of poor recruitment of patients. However, it did help to establish consensus opinion for treatment.^{13,50} If the decision is made to use tPA, the patient requires imaging confirmation of AIS with occlusion of an artery in the distribution of the stroke as well as the absence of intracranial hemorrhage.⁴⁴ The current recommendation is to give tPA at the adult dose of 0.9 mg/kg intravenously, with the first 10% given as a bolus and the remaining dose given over 1 hour. TPA must be given within 4.5 hours of symptom onset.⁴⁸

There have been only small case series looking at endovascular thrombectomy for pediatric AIS. However, many of these case series have demonstrated good outcomes.^{51,52} There are no strong pediatric clinical trial data to guide the decision to attempt endovascular thrombectomy. According to a consensus statement from the American Heart Association/American Stroke Association in 2019, endovascular thrombectomy should be considered only in pediatric patients with persistent disabling neurological deficits (Pediatric NIH stroke scale score > 6) at the time of intervention and radiographically confirmed cerebral large artery occlusion. Additionally, the size of the patient who can receive a thrombectomy is limited by the size of the catheters, the use of contrast dye, and radiation exposure.^{13,53}

Patients with AIS who are not candidates for thrombolysis or endovascular thrombectomy should receive either antiplatelet therapy, such as aspirin, or anticoagulant therapy, such as low molecular weight heparin or unfractionated heparin. Patients with uncharacterized AIS can be started on either while the cause of the stroke is being determined. Consultation with a pediatric hematologist can be beneficial in guiding management.^{13,54}

Decompressive hemicraniectomy is rarely performed in children with AIS. In one study, hemicraniectomy resulted in a low mortality rate of 8%. However, a large percentage had significant neurologic deficits. It could not be determined if this was owing to the stroke, the hemicraniectomy, or both.⁵⁵

7.2 | Cerebral sinus venous thrombosis

The main treatment for CSVT in children is anticoagulation, including intravenous unfractionated heparin, subcutaneous low molecular weight heparin, and oral warfarin. Several studies have shown a low rate of hemorrhage in patients receiving anticoagulation and a significant percentage of thrombus propagation in patients who were not anticoagulated.^{28,56} Surgical intervention and antibiotics may be required for mastoiditis and otitis media, the most common infectious causes of pediatric CSVT.¹³

7.3 | Hemorrhagic stroke

As with pediatric AIS, normothermia and normoglycemia should be maintained in patients with hemorrhagic stroke. Euvolemia should be maintained with isotonic fluids without glucose unless hypoglycemic. Avoid hypotension as normal or even high blood pressure may be required to maintain cerebral perfusion pressure. Consider hyperosmolar therapy, such as mannitol or hypertonic saline, if a patient has signs or symptoms of increased intracranial pressure. Providing adequate sedation and pain control can help to avoid increases in intracranial pressure. Treat seizures aggressively with anticonvulsants and avoid hypoxia and hypercarbia. Correct known coagulopathies if possible. If a patient is currently receiving anticoagulants, they should be held or reversed. A subdural bolt may need to be placed to monitor intracranial pressure. Ultimately, surgical intervention, such as

hematoma evacuation or hemicraniectomy, as well as embolization or resection of a vascular malformation may be necessary.^{13,32}

7.4 | Sickle cell disease

Exchange transfusion is the treatment of choice for sickle cell disease patients with AIS with a goal of decreasing the percentage of hemoglobin S to <30%. If the patient's initial hemoglobin is <10 g/dL, a simple blood transfusion can be started but the hemoglobin should not go above 11 g/dL to avoid hyperviscosity or volume overload. Exchange transfusion will still be necessary in order to decrease the percentage of hemoglobin S to the goal of <30%. If the patient's initial hemoglobin is already >10 g/dL, exchange transfusion should be the initial treatment.^{13,47} Hulbert et al found that children with sickle cell disease with a stroke who received only a simple transfusion had a 50-fold greater incidence of recurrent stroke compared with those who received exchange transfusion.⁵⁷ Additionally, oxygen should be given to keep oxygen saturation >95%. If febrile, antipyretics and empiric intravenous antibiotics should be given.^{13,47}

8 | OUTCOMES

A recent study, using data from the International Pediatric Stroke Study registry, looked at the outcomes of pediatric patients with AIS at discharge and at 2 years following the stroke. Death occurred before hospital discharge in 1.5% of neonates and 3.3% of non-neonates. At 2 years, the majority of patients had a normal outcome and 24.7% had moderate or severe neurological impairment. Neonates had the best outcomes both at discharge and at 2 years. However, there was a small increase in the number of neonates with impairment at 2 years because of deficits that emerged during the rapid development of the first 2 years of life. When patients were further divided into age subgroups, there was a U-shaped curve in outcomes at 2 years with neonates faring the best followed by patients aged 15–18 years. Patients aged 1 month to 1 year had the worst outcomes.⁵⁸

9 | SUMMARY

Strokes also occur in the pediatric population and actually occur most commonly in the perinatal period. Although many pediatric stroke patients will present similarly to adults, the emergency physician must also consider the possibility of stroke in pediatric patients who present with seizures or altered mental status, especially in younger patients. Strokes in children are a medical emergency and require rapid diagnosis and treatment. The use of a stroke alert protocol has been shown to decrease the time to diagnosis. Recanalization therapies, such as tPA and endovascular thrombectomy, are controversial in pediatrics but have shown benefit in small case series. If possible, consultation with pediatric subspecialists experienced in treating strokes can be invaluable in guiding management.

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