Review Article

Management of intracerebral hemorrhage in pediatric neurosurgery

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INTRODUCTION

Pediatric stroke is a relatively rare occurrence, with an annual incidence of 1.2–13 cases per 100,000. Hemorrhagic strokes account for half of these cases.[28] In adults, hemorrhagic strokes are predominantly hypertensive in etiology. However, in the pediatric population, they are frequently associated with vascular lesions such as AVMs (47%), arteriovenous fistulas, or CMs [Table 1].[21] Other causes of ICH in adults, such as amyloid angiopathy or drug-related vascular damage, are rarely seen in the pediatric population. Workup of pediatric ICH should include vascular imaging consisting of either CTA or DSA. An MRI of the brain should be obtained to detect CMs, which are angiographically occult. MR angiography may lack the sensitivity to allow for visualization of the smaller vessels that may be involved with some of these lesions.[25] In a series of 137 patients with ICH described by Hino *et al.*, 9% were found to have an "occult" vascular lesion that was not visualized on first angiogram. The clinical index of suspicion should guide the workup further if a causative lesion cannot be identified upon initial imaging. This may include repeat DSA, which is considered the gold standard for the assessment of vascular lesions. In the setting of clinically symptomatic hemorrhage, any vascular lesion, including AVM, CM, capillary telangiectasias, or developmental venous anomalies, may present in occult fashion, though AVM is most common.[7]

ILLUSTRATIVE CASES

Case 1

A 7-year-old girl presented with acute onset headache, aphasia, and right hemiparesis. She was found to have a large left temporal intracerebral hemorrhage (ICH) and underwent emergent decompressive craniectomy without direct evacuation of hematoma [Figure 1a]. Postoperative imaging studies, including magnetic resonance imaging (MRI) and digital subtraction angiogram (DSA), failed to show a causative lesion [Figures 1b and c]. She went to rehab and had considerable improvement of her

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Table 1: Most common etiologies of spontaneous intracerebral hemorrhage in adults and children

Adults[20]	Children[12]
Hypertensive vasculopathy (35%)	Vascular malformations (50%)
Cerebral amyloid angiopathy (20%)	Arteriovenous malformations (39%)
Bleeding diathesis	Cavernous malformations (11%)
Anticoagulation (14%)	Bleeding diathesis (21%)
Systemic disease-related coagulopathies (5%): liver failure, DIC, congenital, thrombocytopenia	Coagulopathies: liver failure, DIC, congenital
Vascular malformations (5%)	Thrombocytopenias: malignant (ALL, AML), congenital (aplastic anemias, bone marrow failure), immune-mediated, autoimmune
Other (21%)	Aneurysm (9%)
Aneurysm	Hemorrhagic primary intracranial tumor (6%)
Hemorrhagic conversion	Other (10%)
Hemorrhagic primary or metastatic intracranial tumor	Hemorrhagic CNS infection
Hemorrhagic CNS infection	Cerebral vasculitis
Drug abuse (cocaine, amphetamines)	Moyamoya disease
Cerebral vasculitis	Illicit drug abuse
Cerebral venous thrombosis	

Incidences are cited in parentheses. Note the differences in incidence of vascular malformations as the etiology (5% versus 50%). ALL: Acute lymphocytic leukemia, AML: Acute myelocytic leukemia, CNS: Central nervous system, DIC: Disseminated intravascular coagulation, ICH: Intracerebral hemorrhage
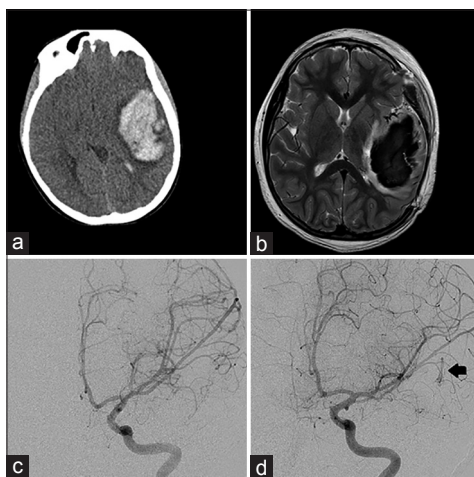

Figure 1: Left frontal hemorrhagic lesion from Case 1. (a) Computed tomography of the head at presentation showed a 9 × 4 × 4 cm hematoma with midline shift. (b) Magnetic resonance imaging brain, T2 sequence showed surrounding vessels but no definite arteriovenous malformation nidus around the large hematoma. (c) Left internal carotid artery digital subtraction angiogram at presentation, without evidence of vascular malformation. (d) Left internal carotid artery digital subtraction angiogram at 4 months post-hemorrhage reveals a left temporal Grade 1 arteriovenous malformation (arrow)

aphasia and hemiparesis. Six weeks later, repeat imaging with DSA was performed after resolution of the initial hemorrhage, which also failed to show an associated vascular lesion. Because of the high index of clinical suspicion for arteriovenous malformation (AVM), a third angiogram was performed at 4 months post-hemorrhage. This showed a small left temporal AVM with a small nidus and early draining vein, which was the likely culprit of the patient's initial hemorrhage [Figure 1d]. Because of its small size, the lesion was not visualized on MRI or computed tomography (CT) angiogram; thus, radiosurgery was not a treatment option. Endovascular embolization was considered but deemed a poor option due to the high degree of difficulty in accessing the feeding vessel and concerns of the durability of treatment in this young patient. Because of the difficulty in localization, DynaCT was performed with the catheter in the feeding vessel from the inferior branch of the left MCA. This allowed preoperative study, planning, and intraoperative neuronavigation.[26] The lesion was successfully resected in total, and cranioplasty was performed in the same setting. Postoperative DSA demonstrated complete extirpation of the AVM, with tissue confirmation by pathology. The patient made an excellent recovery. She is ambulatory without focal motor deficit and has regained normal language function.

Case 2

A 9-year-old girl presented with acute onset of headache and obtundation. CT of the head demonstrated a large right cerebellar hemorrhage with tonsillar herniation, brainstem compression, and obstructive hydrocephalus [Figure 2a]. CT angiography (CTA) was suspicious for a vascular lesion. In emergent fashion, ventriculostomy was placed, followed by posterior fossa decompression. Because of the suspicion of a vascular lesion requiring further characterization, suboccipital decompression with craniectomy and dural decompression and minimal subtotal resection of the hematoma were performed. After surgical stabilization, the patient underwent DSA and MRI, which revealed an AVM, fed by branches of the right anterior and posterior inferior cerebellar arteries (AICA and PICA) [Figure 2b and c]. She returned to the operating room the next day for definitive resection of the AVM. Postoperative DSA confirmed complete extirpation of the ruptured AVM and surrounding hematoma [Figure 2d]. Ventriculostomy was subsequently weaned, and the patient recuperated with rehabilitation. At one-year follow-up, the patient was independent with activities and had returned to school.

Case 3

A 14-year-old girl presented with acute onset of headache, nausea, and vomiting for 1 day. She had similar but mild symptoms 2 weeks prior. She had a generalized seizure
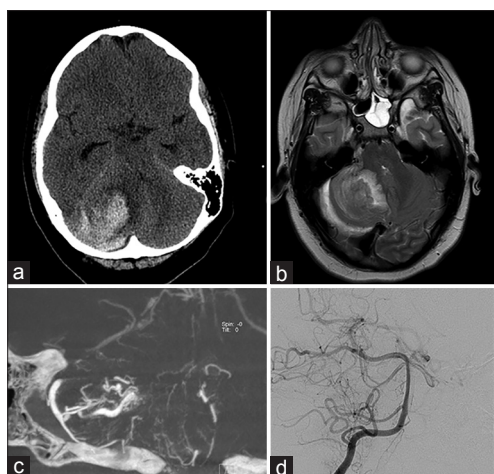
Figure 2: Right cerebellar hemorrhagic lesion from Case 2. (a) Computed tomography of the head at presentation showed a large hemorrhage of the right cerebellar hemisphere with displacement of the fourth ventricle. (b) Magnetic resonance imaging brain, T2 sequence showed perilesional edema and some associated vessels. (c) Right vertebral artery injection DynaCT, coronal view, showed an arteriovenous malformation with feeders from the right anterior and posterior cerebellar arteries. (d) Postoperative angiogram, AP projection, showed no residual malformation
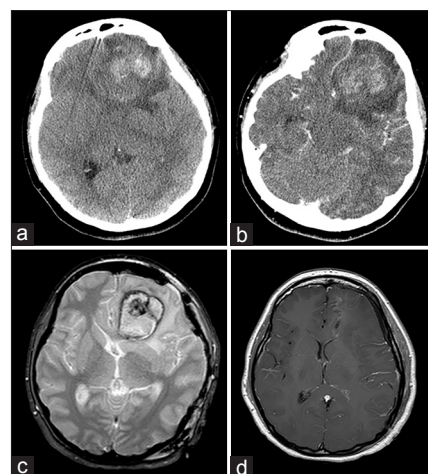

Figure 3: Left frontal hemorrhage from Case 3. (a) Computed tomography of the head showed a large left frontal intracerebral hemorrhage with subfalcine shift and perilesional edema. (b) Computed tomography with contrast showed partial enhancement of the lesion without any vascular feeders. (c) Magnetic resonance imaging brain, gradient echo sequence, showed a central lesion with surrounding hemorrhage, suggestive of cavernous malformation. (d) Postoperative magnetic resonance imaging brain with contrast showed complete resection of the lesion and hematoma, with resolution of mass effect

upon arrival to the hospital. CT of the head revealed a large 5 cm left frontal hemorrhage with mixed density and significant mass effect with exuberant perilesional edema [Figure 3a]. She was intubated for diminished sensorium and subsequently deteriorated as a result of uncal herniation. CT of the head with contrast demonstrated a lesion that appeared to be consistent with a tumor, though not definitive [Figure 3b]. She was taken for emergent decompressive craniectomy for stabilization. Subsequently, she returned to her prior neurological baseline. She proceeded to undergo MRI and MRA of the brain, which were suggestive of a cavernous malformation (CM) rather than a hemorrhagic tumor [Figure 3c]. The lesion was completely resected [Figure 3d], followed by replacement of her bone flap. Pathology confirmed hemorrhage and CM. The patient made an excellent functional recovery, with resolving mild abulia secondary to her dominant frontal lobe injury.

MANAGEMENT

Upon initial diagnosis of intracerebral hemorrhage on noncontrast CT, workup and treatment should be initiated without delay. The guidelines for the treatment of spontaneous ICH were last updated in 2010; these recommendations also apply to pediatric patients [Table 2].[22] Based on institutional availability and clinical suspicion, workup should proceed with both vascular imaging (CTA or DSA) and MRI of the brain. Some authors have reported that MRI, MRA, and MRV are sufficient to diagnose vascular lesions in up to 66%

of patients.[19] We suggest that MR vascular studies be supplemented with their CT-based counterparts if clinical suspicion is high for the improved resolution and sensitivity of CTA as MR imaging has a false-negative rate of 7%.[19] Intensive care and monitoring are indicated. Conservative management with supportive care may be appropriate for self-limited hemorrhage without progressive mass effect or elevated intracranial pressure (ICP).

SURGICAL NUANCES

Several surgical options exist for managing acute ICH requiring intervention. First and foremost are the evaluation and management of "ABCs:" Airway, breathing, and circulation. If high intracranial pressure is present, it must be addressed with external ventricular drainage, evacuation of the hematoma, and/or decompressive craniectomy with expansile duraplasty depending on the clinical situation and the location of the hemorrhage. If there is suspicion of underlying AVM, limited evacuation of the hematoma is advised only if necessary in cases of mass effect because aggressive evacuation of the hematoma may precipitate AVM re-rupture. The thrombus cap over the rupture site can be tenuous.[16] In non-eloquent areas or in the posterior fossa where mass effect can be significant, evacuation of hematoma is typically undertaken with care, cognizant that an underlying AVM may be present.

In hemorrhages seemingly admixed with eloquent brain tissue, our experience supports a large craniectomy

Table 2: Summary of guidelines for management of spontaneous intracerebral hemorrhage

Emergent Management
  Noncontrast head CT to distinguish ICH from ischemic stroke.
  Correction of coagulopathy or thrombocytopenia, if present.
    For pediatric patients: CTA, CTV, contrast CT, MRA, MRV, and
    contrast MRI to rule out vascular malformations or hemorrhagic
    tumors.
Inpatient Management
  Admission to neurological ICU and supportive care:
    Maintenance of CPP with ICP monitoring, ventricular drainage as
    necessary, and cautious normalization of hypertension.
    Anti-epileptics for clinically evident or electrographic seizures.
    Specialized nursing with neurocritical care protocols in place.
  Surgical evacuation for patients with significant mass
  effect (impending or progressing herniation) and/or elevated ICP.
  Staged or same-setting resection of associated hemorrhagic lesion,
  if identified.
Prevention of Recurrence
  Blood pressure control and avoidance of long-term anticoagulation.
    For pediatric patients: Regular neuroimaging (postoperative
    and 1-year DSA, followed by annual CTA or MRA, and DSA
    every 3 years until age 18) to detect recurrence of vascular
    malformations.
Rehabilitation
  Access to a multidisciplinary, integrated inpatient/outpatient
  rehabilitation program as early as possible.

Adapted from AHA/ASA 2010 recommendations.[22] Additional recommendations have been added for management of pediatric patients. CPP: Cerebral perfusion pressure, CT: Computed tomography, CTA: CT angiography, CTV: CT venography, DSA: Digital subtraction angiogram, ICP: Intracranial pressure, ICU: Intensive care unit, MRA: MR angiography, MRI: Magnetic resonance imaging, MRV: MR venography

with expansile duraplasty in cases of significant cerebral edema, without surgical destruction of eloquent areas. This allows for the possibility of recovery of function. Direct removal of the hematoma and the vascular malformation at initial surgery may not be possible due to high ICP and incomplete workup due to clinical instability, and thus, incomplete appreciation for the anatomy and localization of the lesion, as described in Case 1. Craniectomy or minimal evacuation of hematoma, followed by a more lesion-tailored approach with the support of diagnostic imaging, may be prudent in these cases. In contrast to ruptured aneurysms that have a high short-term risk of re-rupture, thus warranting urgent securement, ruptured AVMs and cavernomas have relatively low acute re-rupture rates, which allow slightly more conservative management.[8,9] This permits the benefit of proceeding to surgery under optimal circumstances with adequate imaging and a medically optimized, stable patient. Multiple-modality imaging should be used, and in the case of equivocal findings, repeat imaging is indicated as obscuring hemorrhage resolves. Modern management can include the use of intraoperative indocyanine green videoangiography (ICG-VA) or intraoperative DSA in a hybrid OR-angiography suite.

ARTERIOVENOUS MALFORMATIONS

AVMs are the most common cause of ICH in children. They carry an annual risk of hemorrhage of approximately 3.2%, a 5–10% mortality rate, and a 50% risk of neurological morbidity.[4,23] The large majority of AVMS are clearly evident on DSA, although several authors dating back several decades have described angiographically "occult" AVMs that were obscured following rupture.[24,27] Hypotheses for this phenomenon include possible lesional thrombosis, compressive occlusion of lesion from hematoma, transient vasospasm, or small nidus.[24] The Lawton supplementary scale has been used in recent years as an adjunct to the well-established Spetzler–Martin grading scale for assessment of surgical risk in AVMs.[14,17] The Lawton supplementary scale validates the experience that pediatric patients and lesions with previous hemorrhage carry lower surgical morbidity. This helps to further guide the treatment decision-making in AVM-associated pediatric ICH. While SRS may play a role in lesions with unacceptably high surgical risk,[1] the risk of short-term hemorrhage and lesional persistence is concerning in pediatric patients with a higher cumulative lifetime risk of hemorrhage.[13] With a 20% failure rate of primary SRS therapy, radiosurgery is best used as an adjunct to a more definitive cure in the pediatric patient.[10] Endovascular embolization, frequently performed with Onyx or n-BCA at our center, usually plays an adjunct role to surgical resection but is not used as the primary treatment modality.

Postoperative surveillance of AVM

AVMs in children are fraught with a high recurrence rate (as high as 14%),[23] especially in lesions with a diffuse nidus[15] or deep venous drainage. There are no definitive guidelines for postoperative surveillance, however, undoubtedly, DSA has the highest resolution and sensitivity. Although surveillance patterns vary greatly, at our institution we recommend intraoperative/immediate postoperative DSA, followed by 1-year DSA, yearly CTA, and DSA every 3 years until age 18. Concerns over morbidity of the procedure are discussed, though the overall procedural complication rate is less than 1%.[18] A recent series suggests that MRA, although benign in the sense of radiation and contrast exposure, has reduced sensitivity.[23] CTA is considered as a noninvasive surveillance tool with higher sensitivity at recurrent AVM detection than MRA[23] and is used at our institution at yearly intervals between surveillance DSA performed at 3 years intervals.

CAVERNOUS MALFORMATIONS

CMs represent 20–25% of spontaneous ICH in children.[12] CM-associated ICH is generally smaller

and has better outcomes compared to ICH from AVM. Rarely, CM-associated ICH can produce significant mass effect and may even be fatal.[2] Various factors have been associated with symptomatic hemorrhage risk. Chief among them are prior hemorrhage, brainstem location, and associated developmental venous anomalies (DVAs). The natural history of CMs includes temporal clustering of hemorrhages, often seen within the first 3 years of a herald bleed. This known grouping of hemorrhages should be an important consideration in management.[9] Unhemorrhaged lesions have an annual bleeding rate of <2%, whereas previously hemorrhaged lesions can have much higher rates (4.5–22.6%).[3] The appearance on MRI has been described in four classes by Zabramski *et al*.[30] While the classical "popcorn" appearance (Zabramski Type 2) is the most common, it is important to be familiar with the more atypical appearances as well. CMs are angiographically silent; thus, MRI is the only way to visualize them. Large ICH from CMs can obscure the lesion itself, making initial diagnosis challenging at times.[11,29] The initial hemorrhage can sometimes take months to fully resolve. In pediatric patients with ICH, it is imperative to maintain a high index of suspicion for causative vascular lesions and to continue aggressive diagnostic workup given the relatively high incidence in this population.[5] Therefore, MRI following the resolution of the acute hemorrhage is mandatory to rule out underlying vascular lesions. Advanced MRI sequences, such as gradient echo (GRE) and susceptibility weighted imaging (SWI), have a better sensitivity for blood and may better characterize the lesion[6] or identify other lesions in the setting of multiple CMs. Specifically, because there are no intrinsic 180-degree refocusing pulses in gradient echo sequences (as compared to a spin echo sequences), GRE images are more sensitive to the dephasing and signal losses that result from paramagnetic blood products. SWI further increases sensitivity to dephasing from these blood products by incorporating and mathematically amplifying this phase information in the image generation process. Cavernomas typically have hemosiderin rings on T2-weighted sequences.

CONCLUSION

Intracerebral hemorrhage in children requires special consideration in management compared to the same in adults. The rate of associated vascular malformations, including but not limited to AVMs and CMs, is high. These should be considered during initial evaluation, hematoma management, and surgical management of the offending lesion.[20]

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Conflicts of interest
There are no conflicts of interest.

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