Acute Neurosurgical Conditions

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More than any other system of the human body, the central nervous system (CNS) undergoes exponential transformation during its postnatal development. Therefore, a review of pediatric neurosurgical conditions requires consideration of the age of the child. This article discusses two neurosurgical conditions that require immediate care: raised intracranial pressure (ICP) and spinal cord trauma. Emphasis is placed on the pathogenesis and diagnoses of these conditions to aid the pediatrician in the proper care of the affected child.

Raised Intracranial Pressure

Intracranial pressure is determined by the dynamic interaction between the skull and the intracranial contents (brain, blood, and cerebral spinal fluid [CSF]). The brain occupies 70% of the skull volume, cerebral blood volume occupies 10%, and CSF occupies 10%. That leaves 10% available space for physiological variations while maintaining normal ICP. All three components are considered incompressible. Any change in one will induce changes in one or both of the others.

When a supratentorial mass (tumor, abscess, or hematoma) expands, it displaces the adjacent brain. Reduction of the CSF volume follows, and the lateral ventricle in the hemisphere of the lesion is compressed. The basal cistern may collapse, and the subarachnoid space surrounding the hemispheres virtually disappears. Once the buffering volume capacity of the CSF is exhausted, the brain will herniate below the falx and come through the tentorial incisura. The normal flow of CSF to the posterior fossa is interrupted, and a pressure gradient develops between the hemispheres and the spinal canal. This gradient propels the brain downward, shifts the brain stem, and causes ischemia of the medulla by distorting the central perforating branches of the basilar artery. Simultaneously, the cerebral perfusion pressure (CPP) is reduced, and secondary ischemic brain damage

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occurs. This may be permanent even if the expanding lesion is removed.

If a mass, usually a tumor, expands in the posterior fossa, a different set of events develops. Free CSF flow is obstructed at the level of the fourth ventricle, and dilatation of the lateral ventricles causes an increase in ICP. If the primary lesion is not removed, the child will suffer from direct damage to the brain stem. The cerebellar tonsils will herniate through the foramen magnum, and subsequent medullary compression will lead to the death of the child.

These events occur in all age groups. The following considerations, however, must be kept in mind when treating children with raised ICP.
- Because children have a lower arterial pressure than adults, the risk of a low CPP increases with increased ICP. In infants, the upper limit of normal ICP is 5 mm Hg. In children younger than 5 years of age, 10 mm Hg is normal. Adolescents have an ICP similar to those of adults.1
- In children and adults, the brain arteriolar pressure is considered to be the equivalent of CPP. Arteriolar pressure is one third of the carotid artery pressure and ranges from 15 mm Hg in infants to 40 mm Hg in adolescents and adults. Up to the age of 10 years, a CPP of less than 40 mm Hg may lead to cerebral infarction. A CPP below 20 mm Hg usually leads to death.2
- In contrast to adults, children have a relatively smaller CSF volume. The buffering capacity for any increase in intracranial tissue volume is reduced, so with an increase in ICP, the pediatric brain herniates and conies earlier than the adult brain.
- In children as well as in adults, the elasticity of the dura is the ultimate limiting factor determining the speed of increase of ICP. Therefore, the compliance of the child’s skull does not increase the buffering capacity of the brain, even though gradual expansion of the volume of the intracranial contents results in a larger head.
- When comparing equal increments in intracranial volume, the slope of the increase in ICP is steeper in infants than in adolescents and adults.3
- The pressure volume index represents the volume in milliliters necessary to produce a tenfold rise in ICP.4 The pressure volume index is 8 mL in infants, 12 to 25 mL in children, and 25 to 30 mL in adolescents and adults.5

CLINICAL PRESENTATION
The clinical presentation will vary according to the primary pathology of the lesion. Hemispheric masses close to the motor strip will be discovered earlier than subcortical occipital or frontal tumors. Signs and symptoms do not develop as rapidly in slowly expanding tumors as they do in abscesses or traumatic hematomas. As a consequence of raised ICP, infants may manifest increased head circumference, engorged scalp veins, a bulging anterior fontanelle, and restlessness. In older children, raised ICP may be suspected with early morning headaches, projectile vomiting, oculomotor dysfunction, gait disturbance, and papilledema.

The causes of increased ICP amenable to immediate surgical treatment are related to space-occupying lesions caused by subacute or chronic diseases of the CNS (such as tumors, abscesses, cysts, and hydrocephalus) or head injury.

Subacute or Chronic Increase of Intracranial Volume
Tumors, cysts, hydrocephalus, and abscesses increase the total volume of the intracranial contents. The brain has elastic properties that allow it to be displaced or to shift as a cone. The effectiveness of the volume buffering systems depends on the rate of the volume addition. The relationship between the volume of a progressively expanding mass and ICP is exponential, with little rise of ICP at first, then progressive increase in the ICP as the compensatory volumes of CSF and blood are exhausted. Consequently, any child who has a progressive deterioration of neurological status, especially if there is a noticeable decrease in the level of consciousness, must have an urgent head computed tomography scan. If the scan reveals a space-occupying lesion, the most effective treatment is the removal of the lesion or control of the accompanying hydrocephalus. The surgical procedure selected is determined by the needs of the child. Steroids may temporarily reduce tumor-associated brain edema.

Hydrocephalus
Hydrocephalus is caused by an increase of the total volume of intracranial CSF with a secondary increase in the size of the ventricles and the subarachnoid cisterns. It usually is the result of a congenital or acquired obstruction of the CSF flow pathways. The most common cause of hydrocephalus after the neonatal period is CSF pathway obstruction by a tumor. Although CSF absorption increases with increasing pressure gradients at the arachnoid villi, this compensatory mechanism may not be available in cases of hydrocephalus where the bulk of CSF volume remains stationary in the ventricles and cannot reach the subarachnoid space.
Falls and motor vehicle accidents account for the majority of cases of SCI, thus the management of pediatric SCI usually begins at the site of the accident.

Cerebrospinal fluid is formed at an almost constant rate of 0.2 to 0.3 mL/min. Because ICP increase caused by CSF volume increase is exponential, any child who has hydrocephalus on a CT scan, even in the absence of clear symptoms of increased ICP, should be considered for prompt surgical treatment. This may be either removal of the tumor that obstructs the CSF flow or placement of a ventriculoperitoneal shunt. The latter is a safe procedure that almost immediately corrects the ICP. Medical treatment with acetazolamide or diuretics will not correct the obstruction of CSF flow and should be initiated only with the knowledge of an experienced neurosurgeon.

When confronted with a child with signs and symptoms of raised ICP, the pediatrician should score the level of consciousness of the child. Since 1974, the Glasgow coma scale (GCS) has been accepted universally as a reliable method of grading levels of consciousness in head-injured patients. While the parameters described by the GCS are applicable in older children, those younger than 5 years of age require a different system. Several coma scales have been devised for children. The Simpson Reilly scale is similar to the GCS but also considers normal developmental milestones in childhood, making it more appropriate for the younger child. As a general guideline, any child whose maximum GCS is 8, or 7 on the Simpson Reilly scale, should be immobilized, undergo endotracheal intubation with hyperventilation to produce mild respiratory alkalosis, and the ICP should be monitored continuously.

The methods currently used for continuous ICP monitoring are as follows:
- A ventricular catheter is the preferred method for monitoring ICP when the lateral ventricles can be cannulated. It allows for drainage of CSF to control ICP. Insertion is through an incision just anterior to the coronal suture. Risk of infection is reduced if the cannula is replaced every 5 days and prophylactic antibiotics are instilled through the catheter.
- A fiberoptic pressure-measurement device can be placed in the lateral ventricle, the parenchyma, or the subarachnoid space. Air bubbles or cerebral debris may impair its function, and the device cannot be recalibrated once inserted.
- A subarachnoid bolt does not invade the brain and has a low infection rate, but blockage of the bolt and recording artifacts are frequent. It may be difficult to place the device in the thin skull of an infant.

Considering that an infant’s anterior fontanelle tradionally has served as a clinical reflector of increased ICP, fontanometry theoretically would seem the best method for measuring ICP in infants. Unfortunately, accurate measurement of ICP with fontanometry has proven difficult.

HEAD INJURY

Half of the patients admitted to emergency rooms for head injury are children. Consequently, the primary care pediatrician frequently is involved with patients who have sustained trauma to the CNS. Adequate assessment of the nature and severity of the lesion is essential for determining the therapeutic program to be followed. Of particular importance is recognizing in an awake child those signs and symptoms of CNS trauma that may require prompt surgical treatment. When examining a child who has sustained a head injury, the pediatrician should determine the following: the level of consciousness (GCS or Simpson Reilly scale), the symmetry of the motor responses in all four extremities, the symmetry of the ocular movements and the pupillary response to light, and the integrity of the scalp.

This will lead to one of the following initial findings:
- a GCS of 8 or less (7 on the Simpson Reilly scale),
- An asymmetric motor response and abnormal pupillary response to light,
- a compound skull fracture, or
- a normal neurological examination.

With either of the first two findings, a head CT scan is required immediately. This may reveal either parenchymal edema or an intracranial hematoma. A child with CT scan evidence of cerebral edema without a space-occupying lesion should have aggressive medical treatment. The details of this may be found elsewhere. Steroids have been widely administered to patients with head injury, but numerous studies fail to support the assumption that steroid administration improves the outcome of head injury. The general use of steroids is not recommended.

If the head CT scan shows an intracranial hematoma, a neurosurgeon should be contacted immediately. While the nature of treatment is being determined, the child should be placed in an intensive care unit. The initial goal is to maintain or restore normal arterial oxygenation, blood pressure, and body temperature. Vital signs should be maintained within a normal range. In addition, the head should be elevated (protecting the cervical spine) in patients who are not in, or potentially in, hypovolemic shock.
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spasm of the central sulcal arteries or of the vertebral and anterior spinal arteries. The spinal cord birth injuries may result from excessive longitudinal forces applied when in breech presentation, such as when the legs of the infant are pulled while the head is held by uterine contraction. The neonatal spine possesses extreme elasticity. It can be stretched up to 2 inches without disruption. The cord and meninges, however, can be stretched only one quarter of an inch before anatomic disruption occurs. As a consequence of the cord being tethered by the sacral and lumbar roots, the upper cervical cord and the thoracocervical cord junction of the newborn are vulnerable to traction injury. These injuries are responsible for severe neurological deficit, and the ability of surgical treatment to improve the deficit is limited.

Falls and motor vehicle accidents account for the majority of cases of SCI, thus the management of pediatric SCI usually begins at the site of the accident. Unconscious patients must be suspected of having spinal fracture until proven otherwise. Spinal immobilization is mandatory until all neurological and radiological examinations are completed. As children have large heads in relation to their body size, the use of the standard backboard may be hazardous because the head may be forced forward, causing the neck to flex. To solve this problem, the standard backboard has to be modified, either to lower the head or to raise the chest. Methylprednisolone administered in the early phase of SCI improves the recovery. Prolonged use of steroids does not modify the outcome of children with SCI.

Diagnostic Imaging

Depending on the injury to the child, anteroposterior and lateral radiographs of the spine should be obtained. Often, a single lateral radiograph of the cervical column is sufficient for initial assessment of the severity of the injury. Computed tomography scan or multiplanar tomography can be useful in delineating a spinal fracture or dislocation. In young children, however, ligamentous or cartilaginous lesions can be missed. A spine magnetic resonance image (MRI) is the study of choice in SCI.

Depending on the nature of the SCI, the use of external orthotic devices or halo traction may be
required. The age of the patient and the thickness of the skull has to be considered when cervical dislocations require reduction. Those patients with mild injuries are discharged once their deficit clears. They must wear a brace and refrain from intense physical activity for a minimum of 3 months.

**Surgical Treatment**

Prompt surgical treatment is necessary for extradural or subdural hematomas, compound wounds, ruptured disks, and unstable fractures and dislocations of the vertebral column. Removal of the hematoma, debridement of open wounds, and internal fixation of the spine are the procedures used more frequently in children with SCI.

**Prognosis**

The overall prognosis for functional recovery is discouraging and largely depends on the degree of initial neurological injury. Progressive vertebral column deformity and development of posttraumatic syringomyelia are delayed complications of SCI that may require later surgery. In the more severe cases, the attending pediatrician will continue to be involved with consequences secondary to the original injury. These include pulmonary and urinary tract infections, decubiti, respiratory insufficiency, renal failure, deep vein thromboses, spasticity, and pain.

**SCIWORA**

Special consideration is deserved for spinal cord injuries without evidence of radiological abnormality (SCIWORA). This is an almost exclusive condition of pediatric SCI with a high relative frequency and potential for mismanagement.

Up to the age of 9 years, the child has a larger head-to-torso ratio with underdevelopment of neck and paraspinal musculature. The spine is very elastic with ligamentous laxity, a shallow, horizontal orientation of the facet joints, and an incompletely formed uncinate process. Consequently, a child's vertebral column can withstand traction and torsion without radiological evidence of deformity, yet the spinal cord may be damaged. This type of injury poses a perplexing problem to the pediatrician and neurosurgeon. Even if the radiographs are interpreted correctly as normal, the child may still have an SCI. When possible, children with a history of neck trauma and a normal neurological examination should be questioned regarding paresthesias immediately after the accident. It is recommended that if paresthesias have been present, children should be considered to have an SCI until repeated neurological examination, an MRI of the cord, and somatosensory evoked potentials prove otherwise.

**REFERENCES**