EVERE head injuries in the pediatric population are among the most difficult problems facing a neurosurgeon. In this follow up to a previous article, we include data on five previously reported as well as 11 new cases, for a total of 16 cases. Since the time of the initial report we have established better-defined treatment criteria and have demonstrated justification for intervention. Also, we are comfortable intervening earlier and without the use of barbiturate coma.

Patients who have experienced severe head injury may develop significant and progressive intracranial hypertension without mass lesion. It has always been assumed that lumbar drainage is contraindicated in the setting of head injury because of the possibility of inducing transtentorial or tonsillar herniation. Little information exists regarding the incidence of herniation in the setting of raised intracranial pressure (ICP) and no mass lesion. This report documents 16 pediatric patients with head injury who manifested high ICP resistant to aggressive medical therapy, including ventriculostomy. In each patient, lumbar drainage was instituted to control sustained and elevated ICP.

Clinical Material and Methods

Sixteen pediatric patients with severe head injuries admitted to Children’s Health Center of St. Joseph’s Hospital and Medical Center/Barrow Neurological Institute, Phoenix Children’s Hospital, or Maricopa Medical Center were studied. They ranged in age from 1 to 15 years, and there were five girls and 11 boys. Twenty-four hours after admission, all patients had a Glasgow Coma Scale (GCS) score lower than 8. All patients were managed according to an aggressive protocol of ICP control. After an initial computerized tomography (CT) scan of the head and prompt evacuation of any mass lesions, all patients underwent ventriculostomy placement and were treated by hyperventilation (PCO₂ 28 to 32 mm Hg) and by furosemide and/or mannitol diuretic therapy (serum osmolality 305 to 320). Five of the patients were placed in barbiturate coma, titrated to burst suppression on compressed spectral array monitoring. To monitor cardiac output, the barbiturate coma patients also underwent Swan–Ganz catheterization. Six patients were treated by administration of intermittent barbiturate drugs.
and were not monitored by compressed spectral array for burst suppression. Five patients received no barbiturate agents.

Lumbar drains were placed in the following manner. A No. 14-gauge Touhey needle was used to place a lumbar subarachnoid drain. With the stylet in place and the ICP being monitored, a gradual decompression of cerebrospinal fluid (CSF) was allowed (1–3 minutes). The drains were then connected to a collection system. To prevent development of a pressure gradient, drainage height was set equal with the ventriculostomy, usually 5 to 15 cm above the head. In most cases, lumbar pressure readings were obtained.

Outcome was assessed 6 months postinjury using the categories of the Glasgow Outcome Scale: 1) good recovery, a return to school with average academic performance; 2) moderate disability, capable of thought or capable of developing some level of independent function; 3) severe disability, conscious but requiring constant care; 4) vegetative; and 5) dead. Condition at admission, treatment, and outcome are summarized in Table 1.

### Illustrative Cases

#### Case 2

This 12-year-old girl was a pedestrian when she was struck by a vehicle traveling at approximately 35 mph; she was trapped beneath the car for 20 to 30 minutes. Once extricated, she was disoriented but her mental status improved during transport to the hospital. Her admission GCS score was 14. A CT study of her head revealed a right temporal bone fracture with an underlying 1-cm epidural hematoma limited to one CT slice only.

The patient was admitted to the pediatric intensive care unit for observation, and her neurological status rapidly deteriorated, as evidenced by coma and an enlarging right pupil. A repeat CT scan revealed an enlarging acute right temporoparietal epidural hematoma (Fig. 1 upper left) in addition to a small subdural hematoma (0.5 cm) within the posterior fossa. The patient underwent emergency craniotomy with subtemporal craniectomy for evacuation of the right frontotemporal epidural hematoma. A ventriculostomy was placed immediately postoperatively.

During the 1st postoperative 24 hours, the patient’s ICP was periodically elevated to between 20 and 50 mm Hg. A repeat CT scan, prompted by the elevated ICP, revealed that the epidural hematoma had reaccumulated (Fig. 1 upper right). A diagnosis of disseminated intravascular coagulation was made, and the condition was treated with cryoprecipitate, fresh-frozen plasma, and platelet transfusions. The hematoma was promptly evacuated. The bone flap was left out of the wound on closure (Fig. 1 lower left).

The patient’s postoperative GCS score was 6. The right scalp flap was tense and ICP was elevated to between 25 and 30 mm Hg. A repeat CT scan, prompted by the elevated ICP, revealed that the epidural hematoma had reaccumulated (Fig. 1 upper left). A diagnosis of disseminated intravascular coagulation was made, and the condition was treated with cryoprecipitate, fresh-frozen plasma, and platelet transfusions. The hematoma was promptly evacuated. The bone flap was left out of the wound on closure (Fig. 1 lower left).

<table>
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<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
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<th>Drain ICP (mm Hg)</th>
<th>Lesion</th>
<th>Surgery</th>
<th>Barbiturate rates (day)</th>
<th>Drain Placed (day)</th>
<th>GOS</th>
<th>Follow Up (mos)</th>
<th>ICP (mm Hg)</th>
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* GCSADMIT and GCS24 = Glasgow Coma Scale on admission and at 24 hours; GOS = Glasgow Outcome Scale; ICP pre and post = intracranial pressure pre- and 4 hours postdrain placement; MVA = motor vehicle accident; DAI = diffuse axonal injury; C = coma; ped = pedestrian; EDH = epidural hematoma; ATV = all terrain vehicle; SDH = subdural hematoma; I = intermittent; UL = unable to locate; ICH = intracerebral hemorrhage.
ly was counseled about the danger of persistent high ICP and the risks of placing a lumbar drain as a final therapeutic resort.

Upon placement of the lumbar drain, CSF pressure was noted to be 40 mm Hg, and pressures and output were recorded (Fig. 2 left and right). There was a precipitous decrease in ICP. A follow-up scan with the lumbar drain in place showed small cisterns (Fig. 3 left and center). The patient was weaned from the barbiturates, hyperventilation, and osmotic therapies. A second episode of sustained high ICP occurred secondary to bilateral spontaneous pneumothoraces while the patient was maintained on mechanical ventilation for pneumonia and respiratory failure. This was treated successfully with bilateral tube thoracostomies. A significant and lasting decrease in the patient’s ICP was noted, and her lumbar drain was discontinued on Day 24 of her hospitalization, 5 days after discontinuation of her ventriculostomy. Follow-up CT scans revealed resolution of the brain edema (Fig. 3 right). She was ultimately transferred to the neurorehabilitation service where she regained function to independent ambulation, and the verbal and cognitive ability to resume her preinjury classwork.

Case 11

This 5-year-old boy fell from the back of a pickup truck that was traveling at approximately 50 mph. He presented with a GCS score of 8 and reactive pupils. No mass lesion was seen on CT scan. Ventriculostomy was placed with an opening pressure of 33 mm Hg. Mannitol (serum osmolality 310), hyperventilation (PCO₂ 28), and ventricular drainage decreased the ICP to 15 mm Hg. Within a few hours the ICP began to rise above 30 mm Hg, and the patient exhibited decorticate posturing. Pentobarbital was used to obtain burst suppression barbiturate coma. His ICP came down slightly but cerebral perfusion pressure (CPP) began to fall into the range of 30 mm Hg, and inotropic medications were required to maintain blood
pressure. Subsequent CT scans revealed no mass lesion (Fig. 4 left and right).

After informed consent was obtained, a lumbar drain was placed; the patient’s ICP was 26 mm Hg at that time (Fig. 5). His ICP fell to 12 mm Hg after slow decompression through the Touhey needle. The barbiturates were stopped and CPP improved. The patient was discharged from the hospital 3 weeks after admission. He participated in outpatient rehabilitation and has a mild attention deficit, but is back in school.

Case 14

This 15-year-old, right-handed boy sustained a gunshot wound in which the bullet entered the left orbit and exited the left posterior parietal area. He presented to the hospital with a GCS score of 3 and improved to GCS 4 with resuscitation. His admission CT (Fig. 6 upper) showed left-sided intracerebral hematoma (ICH) with mass effect and shift of midline. Emergency surgery was performed for removal of the ICH and debridement of the entrance and exit wounds (Fig. 6 center). Ventriculostomy was performed and ICP was more than 40 mm Hg. Maximum medical therapy was achieved and the ICP continued to spike to 40 mm Hg. At this time (Fig. 6 lower) his GCS score was 4. A lumbar drain was placed, which decreased the ICP to 12 mm Hg (Fig. 7), where it remained until the drain was removed 5 days later. His GCS score improved to 9 the next day and to 13 the following day. He was transferred to a rehabilitation center 18 days after admission. At 6 months postinjury he retains a right hemiparesis although he walks independently with a brace. He speaks three- or four-word sentences and has made significant improvements in his cognitive deficits and short-term memory.

Results

Of the 16 patients, 14 had an admission GCS score lower than 8, whereas all patients at 24 hours had a GCS score lower than 8. There were seven pedestrian/bicyclists struck by automobiles; two motor vehicle accidents; two suspected nonaccidental traumas; two all terrain vehicle accidents; one fall from a significant height; one fall from a pickup truck; and one gunshot wound. All patients had at least 3 months of follow-up evaluation. Eight had good outcomes; three had moderate outcomes; three had severe

![Fig. 2. Case 2. Left: Patient’s ventricular and lumbar pressures at time of drain insertion. Right: Patient’s mean daily ventricular intracranial pressure (ICP) and mean daily lumbar pressure.](image)

![Fig. 3. Case 2. Left and Center: Postoperative computerized tomography scans obtained after drain placement showing small decompressed cisterns. Right: Scan obtained 5 months after injury.](image)
outcomes; and two died. The follow-up review ranged from 3 to 41 months, with an average of 15 months.

On admission, 15 of the 16 patients had abnormal CT scans. Three patients had diffuse edema with punctate thalamic hemorrhage. Six patients had areas of contusion in the frontotemporal and parietal lobes, and two required surgery. Six patients had diffuse edema. The boy with the gunshot wound was taken to surgery twice, once for debridement and once for evacuation of the hematoma. One patient had a parietal epidural hematoma and underwent evacuation twice. One subdural hematoma was surgically evacuated. On retrospective review of the CT scans, all patients had discernible basilar cisterns, although some were barely visible.

All patients, including those who received barbiturate drugs, developed high ICP resistant to what are considered aggressive therapies. Fourteen of the 16 children had an abrupt and lasting decrease in ICP after placement of the lumbar drain, which obviated the need for continued aggressive medical therapy. In two patients, brainstem compression secondary to massive cerebral edema had occurred before institution of lumbar drainage, as evidenced by nonreactive dilated pupils. Both children progressed to brain death. A xenon cerebral blood flow (CBF) study in one of these children revealed multiple areas of perfusion defects combined with areas of hyperemia. Lumbar drainage was not responsible for herniation in any of the 16 patients.

The external lumbar drain was weaned in the 14 surviving patients by attempting to increase progressively the height of the drainage bag. However, in three patients CSF output correlated with intermittent ICP elevations and remained sufficiently high, requiring placement of a permanent lumboperitoneal shunt.

**Discussion**

In 1 year, approximately 13 pediatric severe head injury (GCS score ≤ 8) patients are treated for elevated ICP with ventriculostomy at our institution. Of these, an average of two to three patients per year fall into the category of elevated ICP unresponsive to aggressive medical therapy and ventriculostomy.

Reports in the literature are pessimistic concerning patients with uncontrollable ICP. We define raised ICP as pressure in excess of 20 mm Hg sustained for over 5 minutes. However, none of the patients in our study was considered for lumbar drainage unless ICPs were sustained above 25 mm Hg, and the patients were receiving aggressive medical therapy. Uncontrolled ICP, if left unabated, can produce ischemic brain damage, because high tissue pressure can compromise CBF, resulting in secondary brain injury. In these patients, we have considered chronic hyperventilation, diuresis to serum osmolality greater than 305, and maximum drainage of CSF through ventriculostomy as aggressive medical therapy when there is no mass lesion. Two alternatives may exist. It is possible that in some or all of these patients, the increased ICP, although extremely high, was indeed a form of benign intracranial hypertension, and these children may have survived without treatment of this hypertension. It is our policy to treat intracranial hypertension,
and we will await further definition of which cases of head injury with intracranial hypertension are truly benign before we consider changing this approach. To date, we have not managed ICP in children by artificially increasing mean arterial pressures to maintain CPP and, therefore, cannot speculate on whether these children would respond to that modality.

Prolonged hyperventilation below \( \text{PaCO}_2 \) of 32 mm Hg during the first few days after severe head injury is thought to increase the risk of ischemic brain injury.\(^\text{19}\) In many instances the barbiturate drugs decrease CPP severely, negating the decrease in ICP they may otherwise afford. The use of vasopressor agents to increase CPP was attempted in only a few patients in our series. We did not want to treat CPP while ignoring ICP in these cases, especially when lumbar drainage was so successful. Barbiturate drugs are also unreliable in their effect on ICP and can cause severe hypotension. This phenomenon was clearly demonstrated in our study (Case 11). Some studies found no difference with respect to prevalence of raised ICP between barbiturate-treated patients and patients treated without barbiturates.\(^\text{17,29}\) Given the potential deleterious effects of barbiturates, including cardiovascular depression, hypotension, sepsis, and dehydration,\(^\text{9}\) an alternative therapy for uncontrollable ICP may be safer. Our thinking has evolved to the point that we no longer believe that a barbiturate coma trial is necessary before instituting lumbar drainage. We recommend placement of a lumbar drain only if and when focal mass lesions are excluded or removed. Focal lesions with mass effect and shift are an absolute contraindication to this procedure, although for small lesions with minimal shift the drain appears to be well tolerated. On the other hand, diffuse edema has not been a contraindication to this procedure provided: 1) a ventricular drain is in place; 2) only a small amount of CSF is released when the drain is placed; and 3) the lumbar drain is hung at the level of the ventricular drain to prevent a CSF gradient from developing. This report describes a series of patients with uncontrollable ICP, half of whom had good outcomes.

In retrospectively reviewing the series, finding open cisterns, no matter how small, was reassuring, and we now use this information in our decision making. All subsequent drain placements using this radiographic finding have lowered ICP and have not resulted in either complications or death.

The mechanisms of diffuse pediatric head injury have only been partly elucidated. Diffuse swelling most likely represents a physiological response to trauma. Based on the Monro–Kellie hypothesis describing the intracranial...
Controlled lumbar drainage in pediatric head injury

compartments,10,18 which has been characterized mathematically by Marmarou,13 the entities contributing to increased volume in this condition include arterial or venous blood, CSF, brain, and extracellular fluid (vasogenic edema). Bruce, et al.,3 emphasize the hyperemic nature of this condition, often observed after acceleration/deceleration brain injury in the pediatric population, whereby the syndrome of malignant brain edema is caused by severe cerebrovascular congestion.

After brain injury, vasogenic edema resulting from endothelial damage with increased white matter water has been treated traditionally with osmotic and loop diuretics in addition to ventricular drainage. Defective autoregulation, altered cerebrovascular tone, hyperemia secondary to systemic shock, hypoxia, and seizures have each been implicated.9 Patients with diffuse swelling who deteriorate may have developed true edema superimposed on hyperemia.11 Less frequently discussed with reference to head injury, but supported by the previous work by Langfitt, et al.,12 and corroborated by investigations from the pediatric neurosurgical laboratory at our institution, is the secondary obstruction of the superior sagittal sinus as a result of intracranial hypertension.20 Such obstruction leads to venous engorgement and low or absent CSF absorption, which is often exacerbated in the setting of posttraumatic venous engorgement and poor or absent CSF absorption, the surgeon’s treatment of choice for patients with this condition, small ventricles preclude drainage of significant volumes of CSF and secondarily of brain extracellular fluid. However, significant volumes of cisternal subarachnoid CSF can be accessed via the lumbar theca.

Based on experimental work in animals, several authors have hypothesized that approximately 30% of the total compliance of the CSF system is contributed by the spinal axis, whereas the remainder is contained within the cranial compartments.27 In fact, the output of CSF from the lumbar drainage systems routinely exceeds the concomitant ventricular output. The condition of high ICP in pseudotumor cerebri has been shown to respond well to lumbar drainage systems routinely exceeding the concomitant ventricular output. The condition of high ICP in pseudotumor cerebri has been shown to respond well to lumbar drainage.19 In the condition of pseudotumor, intracranial hypertension coexists with small ventricular size, as in our patient population. In addition, the sudden introduction of blood into the subarachnoid space, as in trauma, has been shown experimentally to cause intracranial hypertension secondary to an increase in CSF outflow resistance, presumably at the superior sagittal sinus.3,5,7 A complex relationship between elevated ICP and intracranial sinus pressure has been described; in most cases, venous hypertension is observed when ICP is elevated experimentally.12 With diffuse pediatric head injury, brain edema and hyperemia must decrease brain compressibility and thus inhibit ventricular distension, despite CSF absorptive difficulties. Such a multifactorial combination may be modeled, as in pseudotumor cerebri, and may reveal an increased volume of cortical subarachnoid space, decreased lateral ventricular volume, and increased ICP in all brain compartments.23,24 At this point, the system requires a release valve or outlet that cannot be provided by ventricular drainage alone in the presence of collapsed ventricles. External lumbar subarachnoid drainage may provide the necessary outlet to decompress the system by allowing the hemorrhagic CSF an alternative escape route. This system decompression can be considered lifesaving in our 14 surviving patients; however, these are a carefully selected, small group of patients. In the nonsurviving patients, extensive brain parenchymal damage with resultant edema was too far advanced for lumbar drainage to compensate for the elevated ICP. Therefore, in the setting of pediatric head injury with ICP refractory to conventional medical management, controlled lumbar drainage appears to be a valuable treatment that affords an immediate and sustained decrease in ICP in selected patients.

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