

Chapter 7. Intracranial pressure monitoring technology

I. RECOMMENDATIONS

A. Standards. There are insufficient data to support a technology standard for this topic.

B. Guidelines. There are insufficient data to support a technology guideline for this topic.

C. Options. In pediatric patients who require intracranial pressure (ICP) monitoring, a ventricular catheter or an external strain gauge transducer or catheter tip pressure transducer device is an accurate and reliable method of monitoring ICP.

A ventriculostomy catheter device also enables therapeutic cerebrospinal fluid (CSF) drainage.

D. Indications from Adult Guidelines. Recommendations from the adult guidelines (1) were not based on a level of evidence.

A ventricular catheter connected to an external strain gauge is the most accurate, low-cost, and reliable method of monitoring ICP. It also allows therapeutic CSF drainage. ICP transduction via fiberoptic or strain gauge devices placed in ventricular catheters provides similar benefits but at a higher cost.

Parenchymal ICP monitoring with fiberoptic or strain gauge catheter tip transduction is similar to ventricular ICP monitoring but has the potential for measurement drift.

Subarachnoid, subdural, epidural monitors (fluid coupled or pneumatic) and externally placed anterior fontanel monitors are less accurate.

The overall safety of ICP monitoring devices is excellent, with clinically significant complications (e.g., infection and hematoma) occurring infrequently.

II. OVERVIEW

In patients for whom ICP monitoring is indicated, a decision must be made as to what type of monitoring device to use. The optimal ICP monitoring device is one that is accurate, reliable, and cost-effective and that causes minimal patient

morbidity. We reviewed the scientific literature on ICP monitoring in children and adults and propose a ranking based on the currently available technology.

III. PROCESS

We searched Medline and Healthstar from 1966 to 2001 by using the search strategy for this question (see Appendix A) and supplemented the results with literature recommended by peers or identified from reference lists. Of 41 potentially relevant studies, two were used as evidence for this question (Table 1).

IV. SCIENTIFIC FOUNDATION

The scientific discussion of ICP monitoring technology is divided into the following pediatric and adult sections: A. ICP monitoring device accuracy and stability; B. optimal intracranial location of monitor; and C. complications.

A. Intracranial Pressure Monitoring Device Accuracy and Stability. There are no pediatric studies on this topic. In infants, external placement on an open anterior fontanel has been used, but there are no corroborative data on accuracy or stability of the device.

B. Optimal Intracranial Location of Monitor. There are no pediatric studies on this topic.

C. Complications. In a retrospective study of 49 pediatric patients with TBI between 2–16 yrs of age, Gambardella et al. (2) compared the accuracy of Camino catheter measurements of ICP to ventriculostomy catheter measurements. There were 12 ventriculostomy catheters used and 37 intraparenchymal Camino catheters placed. The Glasgow Coma Scale (GCS) scores were as follows: 3 (19%), 4 (8.5%), 5 (12%), 6 (27.5%), 7 (15%), and 8 (10%). The authors found that for patients with GCS between 3 and 4, the Camino catheter measurements averaged 3–4 mm Hg less than the ventriculostomy catheter; for GCS of 4, the Camino averaged 2–3 mm Hg more than the ventriculostomy catheter; and in patients with GCS between 3 and 8,

the Camino averaged 1 mm Hg less than the ventriculostomy catheter. For patients studied on the same day and with the same GCS score, there was good correlation between ICP measurements with the Camino vs. the ventriculostomy catheter ($r = .73-.89$).

Most studies define infection as a positive CSF culture in ventricular and subarachnoid bolt monitors or a positive culture of the intracranial device. A better definition is bacterial colonization of the device rather than infection since there have been no reports in large prospective studies of clinically significant intracranial infections associated with ICP monitoring devices (1). In a prospective uncontrolled case series, Jensen et al. (3) reported complications associated with ICP monitoring technology. They reported no clinically significant infections associated with ICP catheters. However, they studied the incidence of positive bacterial cultures of the catheter tip (i.e., colonization) following removal in 98 children with TBI who received ICP monitoring. Initial placement occurred in the pediatric intensive care unit (54%), emergency department (34%), or operating room (12%). The positive catheter tip culture rate was 7% (all positive for *Staphylococcus aureus*) and did not correlate with where the catheter was initially placed (intensive care unit, $n = 3$; emergency department, $n = 4$; operating room, $n = 0$). The mean duration of catheter placement was 7 days (range, 3–40 days). The average duration of catheters with negative tip cultures was 7.3 days, whereas the duration of those with positive tip cultures was 12.1 days ($p < .013$). However, excluding the one outlier of 40 days, the average duration of those with positive tip cultures was 7.5 days ($p = .7$ compared with those with negative tip cultures). Loss of waveform occurred in 13% of catheters, occurring at a mean of 9.5 days (range, 3–15 days). Finally, in catheters that suffered loss of waveform, the average ICP mean value was 11.1 mm Hg (range, 4–23 mm Hg) greater than measured when the catheter was replaced.

Table 1. Evidence table

Reference	Description of Study	Data Class	Conclusion
Gambardella et al. (2), 1993	Retrospective study of 49 patients that evaluated correlation between intraparenchymal Camino and ventriculostomy ICP catheters.	III	Good correlation between ICP measurements with the Camino vs. ventriculostomy catheter ($r = .73-.89$), with differences ranging from 1 to 4 mm Hg.
Jensen et al. (3), 1997	Prospective uncontrolled case series of 98 patients with 12 ventriculostomy catheters and 37 intraparenchymal Camino catheters placed.	III	Infectious complication rate was 7% (all positive for <i>Staphylococcus aureus</i>). Loss of waveform occurred in 13% of catheters occurring at a mean of 9.5 days (range, 4–7 days). Data support low incidence of infection and mechanical failure.

ICP, intracranial pressure.

Key Elements from the Adult Guidelines Relevant to Pediatric TBI

A. Intracranial Pressure Monitoring Device Accuracy and Stability. The following information is quoted from the “Guidelines for the Management of [Adult] Severe Traumatic Brain Injury” (1).

The Association for the Advancement of Medical Instrumentation has developed the American National Standard for Intracranial Pressure Monitoring Devices in association with a neurosurgery committee (4). The purpose of this standard is to provide labeling, safety, and performance requirements and to test methods that will help ensure a reasonable level of safety and effectiveness of devices intended for use in the measurement of ICP.

According to the Association for the Advancement of Medical Instrumentation’s standard, an ICP device should have the following specifications:

Pressure range: 1–100 mm Hg

Accuracy: ± 2 mm Hg in range of 0–20 mm Hg

Maximum error: 10% in range of 20–100 mm Hg

Current ICP monitors allow pressure transduction by external strain gauge, catheter tip strain gauge, and catheter tip fiberoptic technology. External strain gauge transducers are coupled to the patient’s intracranial space via fluid-filled lines, whereas catheter tip transducer technologies are placed intracranially. External strain gauge transducers are accurate and can be recalibrated, but obstruction of the fluid couple can cause inaccuracy. In addition, the external transducer must be consistently maintained at a fixed reference point relative to the patient’s head to avoid measurement error.

Catheter tip strain gauge or fiberoptic devices are calibrated before intracranial

insertion and cannot be recalibrated once inserted (without an associated ventricular catheter). Consequently, if the device measurement drifts and is not recalibrated, there is potential for an inaccurate measurement especially if the ICP monitor is used for several days.

There is potential for significant ICP measurement drift with fiberoptic pressure transduction and strain gauge pressure transduction in the parenchymal space. However, adult studies of catheter tip strain gauge ICP devices have demonstrated low or negligible drift over 5 days (1). The accuracy of a pressure transduction device can be assessed by placing the device within the lumen of a ventricular catheter and comparing the fluid-coupled ventricular pressure reading to the device being tested. Catheter tip fiberoptic and strain gauge devices tested in this manner show differences ($> \pm 2$ mm Hg) compared with ventricular ICP readings. This method of pressure transduction comparison may be erroneous when the ventricular catheter is misplaced or occluded.

B. Optimal Intracranial Location of Monitor. The following information is quoted from the “Guidelines for the Management of [Adult] Severe Traumatic Brain Injury” (1).

A pressure transduction device for ICP monitoring can be placed in the epidural, subdural, subarachnoid, parenchymal, or ventricular location.

Historically, ventricular ICP is used as the reference standard in comparing the accuracy of ICP monitors in other intracranial compartments (4). It also has the therapeutic benefit of draining CSF in the event of intracranial hypertension. The potential risks of catheter misplacement, infection, hemorrhage, and obstruction have led to alternative intracranial sites for ICP monitoring.

The following statements ensue from review of the adult and pediatric literature:

- Ventricular pressure measurement is the reference standard for ICP monitoring.
- ICP measurement by parenchymal catheter tip strain gauge pressure transduction or a subdural catheter fluid-coupled device is similar to ventricular ICP. However, some investigators have found that subdural and parenchymal fiberoptic catheter tip pressure monitoring does not always correlate well with ventricular ICP.
- Fluid-coupled epidural devices or subarachnoid bolts and pneumatic epidural devices are less accurate than ventricular ICP monitors. Significant differences in readings have been demonstrated between catheter tip strain gauge ICP devices that are placed in the parenchyma vs. the subdural space.

C. Complications. The following paragraph is abstracted from the “Guidelines for the Management of [Adult] Severe Traumatic Brain Injury” (1).

The complication rate for ICP monitoring is low. The most common complications are infection and loss of waveform. There are no pediatric reports documenting the incidence of significant brain injury, hemorrhage, or seizures as a result of ICP monitoring. There are no pediatric data on the use of prophylactic antibiotics to prevent infectious complications. In patients with ventriculostomy catheters who require continuous CSF drainage, ICP cannot be measured simultaneously. Although complications rarely produce long-term morbidity in patients, they can increase cost by requiring replacement of the monitor, and they can give inaccurate ICP readings. Each type of pressure transduction system and intracranial location of the monitor has a profile of potential complications. Calibration, monitoring for infection, and checking fluid coupled devices for ob-

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struction are necessary tasks in maintaining an optimal ICP monitoring system.

V. SUMMARY

In pediatric patients who require ICP monitoring, a ventricular catheter and/or an external strain gauge transducer or catheter tip pressure transducer device is an accurate and reliable method of monitoring ICP. A ventriculostomy catheter device also enables therapeutic CSF drainage. Clinically significant infections associated with ICP devices causing patient morbidity are rare and should not deter the decision to monitor ICP. The incidence of other complications, such as hemorrhage or seizures, is unknown, but the absence of reported incidents in the

pediatric literature suggests that the incidence is probably low.

Parenchymal catheter tip pressure transducer devices measure ICP similar to ventricular ICP pressure but have the potential for measurement differences and drift due to the inability to recalibrate. These devices are advantageous when ventricular access is limited or unavailable or if there is obstruction in the fluid couple. There are no credible data (class III or better) on the accuracy of subarachnoid or subdural-coupled devices, epidural ICP devices, or externally placed anterior fontanel devices.

VI. KEY ISSUES FOR FUTURE INVESTIGATION

Prospective clinical studies in pediatric patients of the accuracy and complication rate of ventricular and intraparenchymal ICP measuring devices need to be performed. An industry or Food and Drug Administration supported national pediatric registry should be established to collect information on this and other issues in pediatric medicine.

The specification standard for pediatric ICP monitoring should include *in vivo* clinical ICP drift measurement. *In vitro* testing devices do not necessarily reflect clinical performance. Specifications for ICP devices should be reviewed in the context of what data are useful in the management of patients who require ICP monitoring.

A study of simultaneous parenchymal and ventricular ICP measurements using an accurate catheter tip transducer device

in children would be useful. We must answer the question: Does parenchymal monitoring in or near a contusion site provide ICP data that improve intracranial pressure management and outcome compared with other sites (including contralateral sites) of ICP monitoring in children?

Recommendations for the use of prophylactic antibiotics, surgical techniques, ICP data collection, monitoring for complications, and timing for removal of ICP monitoring devices in children need to be developed. Further improvement in ICP monitoring technology should focus on developing an ICP device that can provide ventricular CSF drainage and parenchymal ICP measurement simultaneously. This would allow *in situ* recalibration and give accurate ICP measurements in case of fluid obstruction or when CSF is actively drained. Noninvasive measurements of ICP need to be developed.

REFERENCES

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3. Jensen RL, Hahn YS, Ciro E: Risk factors of intracranial pressure monitoring in children with fiberoptic devices: A critical review. *Surg Neurol* 1997; 47:16–22
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APPENDIX: LITERATURE SEARCH STRATEGIES

SEARCHED MEDLINE AND HEALTHSTAR FROM 1966 TO 2001

Chapter 7. ICP Monitoring Technology

1. exp craniocerebral trauma/
2. head injur\$.tw.
3. brain injur\$.tw.
4. 1 or 2 or 3
5. intracranial pressure/ or “intracranial pressure”.mp.
6. intracranial hypertension/ or “intracranial hypertension”.mp.
7. 5 or 6
8. 4 and 7
9. limit 8 to (newborn infant <birth to 1 month> or infant <1 to 23 months> or preschool child <2 to 5 years> or child <6 to 12 years> or adolescence <13 to 18 years>)