Complications following intracranial pressure monitoring in children: a 6-year single-center experience

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OBJECTIVE Intracranial pressure (ICP) monitoring is an important tool in the neurosurgeon’s armamentarium and is used for a wide range of indications. There are many different ICP monitors available, of which fiber-optic intraparenchymal devices are very popular. Here, the authors document their experience performing ICP monitoring from 2005 to 2015 and specifically complication rates following insertion of the Microsensor ICP monitor.

METHODS A retrospective case series review of all patients who underwent ICP monitoring over a 10-year period from 2005 to 2015 was performed.

RESULTS There were 385 separate operations with an overall complication rate of 8.3% (32 of 385 cases). Hardware failure occurred in 4.2% of cases, the CSF leakage rate was 3.6%, the postoperative hemorrhage rate was 0.5%, and there was 1 case of infection (0.3% of cases). Only patients with hardware problems required further surgery as a result of their complications, and no patient had any permanent morbidity or mortality from the procedure. Younger patients (p = 0.001) and patients with pathologically high ICP (13% of patients with high ICP vs 6.5% of patients with normal ICP; p = 0.04) were significantly more likely to have complications. There was no significant difference in the complication rates between general neurosurgical patients and craniofacial patients (7.6% vs 8.8%, respectively; p = 0.67).

CONCLUSIONS Intraparenchymal ICP monitoring is a safe procedure associated with low complications and morbidity in the pediatric craniofacial and neurosurgical population and should be offered to appropriate patients to assess ICP with the reassurance of the safety record reported in this study.

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KEY WORDS ICP monitoring; intracranial pressure; craniosynostosis; trauma; pediatric

SINCE its introduction in the 1950s,14 continuous intracranial pressure (ICP) monitoring has become an important tool in the modern neurosurgeon’s armamentarium. It has been used for various indications, including trauma,2,3 assessment of hydrocephalus,9 shunt function,17 and craniosynostosis,21 in both adult and pediatric populations.

The gold standard for ICP monitoring has been to transduce ventricular pressure through an external ventricular drain. This also allows management of elevated ICP through CSF drainage. However, the use of an external ventricular drain is associated with a significant risk of infection,6 misplacement,5,15 and hemorrhage.3,15 Advancements in technology have resulted in a much wider range of available ICP monitors, with fiber-optic intraparenchymal pressure monitors now favored by many neurosurgeons. These are easier and faster to introduce with a supposed lower complication rate. Comparison studies examining intraventricular versus intraparenchymal catheters have shown a reduced complication rate in general (29.4% vs 4.4%; p < 0.01)2 and, more specifically, a reduced infection rate (9.2% vs 0.8%; p < 0.01).3 The disadvantages of intraparenchymal ICP monitoring over intraventricular options are the inability to treat any increase in ICP and the
risk of drifting ICP readings over time. Many studies look at the potential for zero drift over time and show that, on the whole, it is relatively minor (median drift 1–2 mm Hg over an average of 7–9 days).\textsuperscript{1,10,18} with good correlation between intraventricular and intraparenchymal pressure readings.\textsuperscript{1,20} Many studies have evaluated the efficacy of such ICP monitors, especially the Camino device,\textsuperscript{3,4,17} but very few look at the overall complication rates for these devices, especially in pediatric populations.

At the Department of Paediatric Neurosurgery at John Radcliffe Hospital, we have routinely used the Codman Microsensor ICP monitoring device (DePuy Synthes) since 2005. Here, we document our experience of using ICP monitoring in a pediatric population over a 6-year period from 2009 to 2015 and look specifically at the complication rate and safety of such ICP monitors.

**Methods**

A retrospective review was performed of the medical records of all pediatric craniofacial patients who underwent ICP monitoring at John Radcliffe Hospital between 2005 to 2015. In total, 663 ICP monitors were inserted. However, we have only been able to accurately collate data since electronic discharge records were instituted in 2009; therefore, detailed analysis was performed on patients who underwent surgery between January 12, 2009, and January 12, 2015.

**Operative Technique**

All patients had a Codman Microsensor intraparenchymal ICP monitor inserted under general anesthesia. A linear parasagittal incision, no more than 1 cm, was used behind the hairline on the midpupillary line. A twist-drill burr hole was placed directly under the incision, and durotomy was performed. A tunneling needle was then used to tunnel the ICP monitor about 5 cm away from the burr hole. The ICP monitor was then calibrated according to the manufacturer’s instructions before being inserted 1–2 cm into the brain parenchyma. The wound was closed, and the ICP monitor was coiled and secured to the scalp.

**Postoperative Recording**

Patients were transferred to the pediatric neurosurgery ward, or rarely the pediatric intensive care unit, for ICP recording using PowerLab (ADI Instruments). For patients with traumatic brain injury, the ICP monitor was left in until the patient was awake and clinically assessable. For all other patients, ICP monitoring was performed for 24–48 hours. If the ICP measurements were obviously normal or abnormal, ICP monitoring was concluded after 24 hours because in our early experience an additional 24 hours of monitoring does not alter the interpretation of the ICP recordings. If there was any uncertainty, an additional 24 hours of ICP monitoring was performed. The ICP monitor was removed on the ward, and the exit wound was only sutured if a persistent CSF leak developed (i.e., a CSF leak that did not settle with a simple pressure dressing). A mean ICP greater than 15 mm Hg or more than 3 B waves in a 24-hour period during sleep were used to classify high ICP.\textsuperscript{21} Patients did not undergo routine postoperative imaging to investigate hemorrhage. This was only performed based on symptomatology.

**Statistical Analysis**

Statistical analysis was performed using Minitab statistical software (version 16, Minitab Inc.). The outcome of interest was the complication rate of ICP monitoring, including hemorrhage, infection, CSF leak, and hardware failure. Predictors of interest included ICP (normal or high pressure), age at surgery (months), indication for ICP monitoring (craniosynostosis or general neurosurgical indications), and surgeon experience (consultant or trainee [registrars or fellows]). Univariate logistic regression modeling was used to describe the association of each predictor with the outcome. Further subgroup analysis was performed on patients with craniosynostosis.

**Results**

From 2009 to 2015, 385 ICP monitors were inserted in 291 pediatric patients. A number of patients had multiple presentations and admissions during the study period with symptoms of raised ICP that warranted ICP monitoring. There were 48 patients with 2 separate ICP monitor insertions, 4 patients with 3 ICP monitors, 6 patients with 4 ICP monitors, 1 patient with 5 ICP monitors, 1 patient with 6 ICP monitors, and 1 patient with 11 ICP monitors. Of these patients, 8 patients had a second operation to replace a faulty ICP monitor. No patient had more than 2 operations during a single admission. Twenty-nine (7.53%) operations were performed by consultants, and the remaining 356 operations (92.47%) were performed by trainees. The mean age at operation was 8 years 3 months (range 0 months to 18 years 7 months) (Table 1). The indications for ICP monitoring are summarized in Table 2. One hundred twenty-five (55%) of the operations in patients with craniosynostosis were performed in patients with nonsyndromic craniosynostosis, and 102 of the operations (45%) were performed in patients who had craniosynostosis associated with an underlying syndrome.

There was an overall complication rate of 8.3% (32 of 385 cases), and most complications were due to hardware failure (16 cases; 4.2%) or CSF leak (14 cases; 3.6%). There were 2 cases of postoperative hemorrhage (0.5%) and 1 case of infection (0.3%). Of the 16 hardware problems, the ICP monitor wire snapped in 4 patients, 2 patients had problems with ICP monitor removal, and the rest were due to innate problems with the ICP transducer.

**TABLE 1. Demographics of the cohort and surgeon experience**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age</td>
<td>8 yrs 3 mos</td>
</tr>
<tr>
<td>Sex, %</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>52</td>
</tr>
<tr>
<td>Female</td>
<td>48</td>
</tr>
<tr>
<td>Surgeon experience, n</td>
<td></td>
</tr>
<tr>
<td>Consultant</td>
<td>29</td>
</tr>
<tr>
<td>Trainee</td>
<td>356</td>
</tr>
</tbody>
</table>
wire. Nine patients required further operations due to hardware problems (8 patients had replacement ICP monitors inserted, and 1 patient required exploration and removal of wire under general anesthesia). One patient had a hemorrhage that required extension of the twist-drill craniostomy to minicraniotomy to stop dural bleeding; the other patient was treated conservatively and did not require any further intervention. One patient developed postoperative meningitis; this patient had ICP monitoring after foramen magnum decompression and presented with irritability. Contents from lumbar puncture tested positive for *Staphylococcus*, and the patient was treated with 10 days of intravenous antibiotics and was discharged in good condition. It is not possible to attribute this infection to ICP monitor insertion or the original foramen magnum decompression. No patients had any permanent morbidity or mortality from ICP monitoring.

The subgroup analysis performed to determine any predictive factors for complications (Table 3) shows that there is a strong negative correlation between age and complication rate (OR 0.85, p = 0.001), with younger patients more likely to have a CSF leak (OR 0.82, p = 0.01) and hardware failure (OR 0.88, p = 0.05). Patients who were deemed to have abnormally high ICP readings were more likely to have complications (13.0% vs 6.5%; OR 2.14, p = 0.04). Interestingly, this was due to increased rates of hardware failure (7.4% vs 2.9%; OR 2.69, p = 0.05) rather than increased rates of CSF leakage (5.6% vs 2.9%; OR 1.98, p = 0.22). This may be due to the fact that the definition of CSF leakage was very broad and included all patients who had a small CSF leak at any time during their stay. This is discussed in detail later. There was no significant difference in complication rates when looking at surgeon experience (8.7% for trainees vs 3.4% for consultants; OR 2.67, p = 0.34). The low risk of hemorrhage and infection did not allow for any further statistical evaluation. There was also no significant difference in the complication rates between general neurosurgical patients and patients with craniosynostosis (7.6% vs 8.8%; OR 1.0, p = 0.67).

Further subgroup analysis was performed for the patients with craniosynostosis who underwent ICP monitoring (Table 4). From this it can be seen that, again, younger age at surgery confers a higher risk of complication (OR 0.85, p = 0.02), which was primarily due to an increased risk of hardware failure (OR 0.77, p = 0.04). There was a trend toward a high complication rate in nonsyndromic patients (11.2% vs 5.9%; OR 0.5, p = 0.17) and patients who had abnormally high ICP recordings (13.6% vs 6.6%; OR 2.22, p = 0.10). Again, there was no significant difference in the complication rates of trainees compared with consultants (5.3% vs 9.1%; OR 1.81, p = 0.57).

**Discussion**

This study reports the largest assessment of ICP monitoring complication rates in a pediatric population to date. More extensive data exist on the complication rates of ICP monitoring using the intraparenchymal Codman Microsensor to treat patients with traumatic brain injury. A study of 303 children who underwent ICP monitoring for traumatic brain injury, meningitis, encephalitis, intracranial hemorrhage, and hydrocephalus reported a complication rate of 4.2%, including 8 cases of hardware malfunction, 1 case of infection, 1 case of hemorrhage in a patient with a low platelet count, and 3 cases of accidental displacement. A smaller study of ICP monitoring in pediatric patients with trauma reported a complication rate of 13%. Our complication rate of 8.3% is similar to the evidence in the literature. We analyzed and reported the complication rate as per operation because we believe that each implantation is an independent event, and data presented in this way offer the most utility to surgeons when evaluating patients. We have not reported the complication rate per patient because this figure is dependent on both the risks of surgery and the probability of multiple presentations during our study period, which is more individualized risk per patient.

**Hardware Malfunction**

Hardware failure was deemed to have occurred if the ICP readings suddenly stopped or became erratic. This was due to either an innate fault in the ICP monitor or external factors, such as the ICP monitor wire snapping or fluid getting into the connector. In all cases, the ICP monitor had to be replaced surgically, either on the same day or at a later date. It would be expected that there should be an even distribution of hardware failure throughout the cohort, as this should essentially be a random event. However, older patients were less likely to have hardware failure than younger patients (OR 0.88, p = 0.05). This may reflect the fact that older patients are likely to be more cooperative and better able to look after the ICP monitor.

**CSF Leakage**

The definition of CSF leakage used in this study was very broad and ranged from small CSF leaks following ICP monitor removal, which settled a few hours after applying a compression dressing, to significant CSF leakage during ICP recording that necessitated early conclusion of ICP monitoring. In only 2 cases did the CSF leak not stop; the ICP monitor was removed, and a skin stitch was inserted to stop the leak. In both of these patients, the measured ICP was high and the CSF leak was strongly suggestive of increased ICP in itself. No patients required a further operation to stop the CSF leak. Thus, if we included only clinically significant CSF leaks (i.e., those that did not settle with simple measures and required stitching) in our
<table>
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<tr>
<th>Variable</th>
<th>Total</th>
<th>Any Complication</th>
<th>CSF Leak</th>
<th>Hardware Problem</th>
<th>Infection</th>
<th>Hemorrhage</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>No. of Cases (%)</td>
<td>OR (95% CI)</td>
<td>p Value</td>
<td>No. of Cases (%)</td>
<td>OR (95% CI)</td>
<td>p Value</td>
</tr>
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<tr>
<td>No</td>
<td>283</td>
<td>26 (9.2)</td>
<td>1.00</td>
<td>9 (3.2)</td>
<td>1.00</td>
<td>15 (5.3)</td>
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<tr>
<td>Yes</td>
<td>102</td>
<td>6 (5.9)</td>
<td>0.62 (0.25–1.55)</td>
<td>0.30</td>
<td>5 (4.9)</td>
<td>1.57 (0.51–4.80)</td>
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<tr>
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<tr>
<td>Normal</td>
<td>277</td>
<td>18 (6.5)</td>
<td>1.00</td>
<td>8 (2.9)</td>
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<td>8 (2.9)</td>
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<tr>
<td>High</td>
<td>108</td>
<td>14 (13)</td>
<td>2.14 (1.03–4.48)</td>
<td>0.04*</td>
<td>6 (5.6)</td>
<td>1.98 (0.67–5.84)</td>
</tr>
<tr>
<td>Surgeon experience</td>
<td></td>
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<td></td>
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<tr>
<td>Consultant</td>
<td>29</td>
<td>1 (3.4)</td>
<td>1.00</td>
<td>1 (3.4)</td>
<td>1.00</td>
<td>0 (0)</td>
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<tr>
<td>Trainee</td>
<td>356</td>
<td>31 (8.7)</td>
<td>2.67 (0.35–20.30)</td>
<td>0.34</td>
<td>1 (3.7)</td>
<td>1.06 (0.13–8.41)</td>
</tr>
<tr>
<td>Age at operation</td>
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<td></td>
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<tr>
<td>&lt;0.01*</td>
<td>0.85</td>
<td>0.78–0.94</td>
<td>0.01*</td>
<td>0.82</td>
<td>0.70–0.95</td>
<td>0.05*</td>
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<tr>
<td>General</td>
<td>158</td>
<td>12 (7.6)</td>
<td>1.00</td>
<td>4 (2.5)</td>
<td>1.00</td>
<td>8 (5.1)</td>
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<tr>
<td>Craniofacial</td>
<td>227</td>
<td>20 (8.8)</td>
<td>1.18 (0.56–2.48)</td>
<td>0.67</td>
<td>10 (4.4)</td>
<td>1.77 (0.55–5.76)</td>
</tr>
<tr>
<td>Overall</td>
<td>385</td>
<td>32 (8.3)</td>
<td>14 (3.6)</td>
<td>16 (4.2)</td>
<td>1 (0.3)</td>
<td>2 (0.5)</td>
</tr>
</tbody>
</table>

* Statistically significant at p < 0.05.
calculation of complications, the overall complication rate would decrease to 5.1% (20 of 385 cases), with a CSF leakage rate of 0.5%.

The subgroup analysis shows that the rate of CSF leakage was evenly distributed whether ICP was high or not. This may be somewhat surprising because it might be expected that there would be a higher incidence of CSF leakage if the ICP were raised, as there is a stronger driving force to expel CSF. However, looking more closely at the data, CSF leakage with an ICP monitor still in situ was exclusively associated with high ICP, and this finding showed high specificity but low sensitivity toward abnormally raised ICP. In addition, CSF leakage was significantly more likely to occur in younger patients (OR 0.82, p = 0.01). Again, the reason for this is not clear but may reflect that a CSF leak is more likely to occur in a less developed scalp.

**Craniosynostosis**

Two previous studies reported complication rates for ICP monitoring using intraparenchymal devices in patients with craniosynostosis. A study of 121 patients reported a complication rate of 2.5% (3 of 121 patients), including 2 cases of CSF leakage and 1 case of local wound infection. A smaller study of 21 cases of ICP monitoring in patients with craniosynostosis reported a complication rate of 14.2%, as represented by 3 cases of CSF leakage. Again, subgroup analysis of patients with craniosynostosis in our data series is similar to the existing literature with an overall complication rate of 8.8% (20 of 227) compared with 7.6% in the general neurosurgical population (p = 0.67). This is important because there is a lack of consensus in the literature regarding the use of ICP monitoring in craniofacial patients. In some units, ICP monitoring is not used as a regular diagnostic tool due to the invasive nature of the procedure and the fear of complications. However, recent studies have suggested that the incidence of raised ICP in nonsyndromic patients is underestimated in the literature. Wall et al. suggest that ICP monitoring should be considered in all patients for whom nonoperative management is contemplated. This study shows that there is a low complication rate and minimal morbidity associated with ICP monitoring. We believe that ICP monitoring is a valuable investigative tool and propose that it is beneficial for the assessment of patients with craniosynostosis.

**Surgeon Experience**

There was no significant difference in the complication rate between operations performed by consultants and those performed by trainees (8.7% vs 3.4%; OR 2.67, p = 0.34). This likely reflects the relatively straightforward nature of the procedure.

**Conclusions**

Here, we present our experience using the Codman Microsensor ICP monitor in a pediatric population. We have, to the best of our knowledge, the largest data set to date in which complications following ICP monitor insertion have been evaluated. In total, 385 separate operations were performed with an overall complication rate of 8.3%.
which is similar to the literature, with minimal associated morbidity and no mortality. The highest complication rate was hardware failure at 4.2%, followed by CSF leakage (3.6%), and only 0.5% of patients had clinically significant leakage. There were 2 cases of postoperative hemorrhage and 1 case of infection. Younger patients were significantly more likely to have complications than older patients, although there was no permanent morbidity or mortality associated with this. Although young age should be taken into consideration, we believe that it should not be a contraindication to ICP monitoring in the younger population. The complication rates were not significantly different in the craniosynostosis cohort compared with the general neurosurgical cohort. Therefore, we suggest that intraparenchymal ICP monitoring is a quick and safe procedure and should be offered to appropriate patients to assess ICP.

References


Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Ma, Magdum, Wall. Acquisition of data: Ma, Rowland. Analysis and interpretation of data: Ma, Rowland, Judge. Drafting the article: Ma, Rowland. Critically revising the article: Ma, Calisto, Jayamohan, Johnson, Richards, Magdum, Wall. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Ma. Statistical analysis: Judge. Study supervision: Ma, Magdum, Wall.

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