Review Article

INTRACRANIAL PRESSURE MONITORING: CONCEPTS IN EVALUATION AND MEASUREMENT

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SUMMARY

Intracranial pressure (ICP) measurement is an extremely important part of the neurosurgical armamentarium. The raised ICP the is not only the commonest cause of death in neurosurgical patients, it is extremely common in patients suffering from head injury. The effective treatment of raise ICP has been shown to decrease mortality. Obviously, an understanding of the principles of ICP measurement is an important prerequisite consideration to the disturbances of brain function that follow head injury. ICP monitoring has been used in subarachnoid hemorrhage, hydrocephalus, brain tumors, infarctions, non traumatic intracerebral hemorrhage, prognostication and treatment, but the most prominent use is in the field of head trauma. Since the preponderance of available literature deals with its use in trauma, the greater part of this review will inevitably deal with head injury.

KEYWORDS: Intracranial pressure, Measurement, Monitoring, Outcome.

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INTRODUCTION

Intracranial pressure (ICP) has been systematically measured only from the last half of a century, but the concept of raised pressure has been known for centuries, and was measured metrically by Quincke in 1897.[1] The seminal publication on ICP monitoring was by Guillame and Janny in 1951. This study unfortunately did not gain the publicity it deserved as it was published only in French. The first widely read paper on systematic ICP monitoring was by Lundberg in 1960, in which he acknowledged Janny's earlier work. Subsequently there have been numerous important publications on the incidence, pathophysiology and influence of raised ICP on outcome from various intracranial pathologies, but the next major impetus towards increasing the incidence of routine ICP monitoring was the publication of the Brain Trauma Foundation guidelines in 1995 and their updates in 2000.[2] ICP monitoring has been used in subarachnoid hemorrhage, hydrocephalus, brain tumors, infarctions, nontraumatic intracerebral hemorrhage, prognostication and treatment, but the most prominent use is in the field of head trauma. Since the preponderance of available literature deals with its use in trauma, the greater part of this review will inevitably deal with head injury.

Patho-physiology: The fundamental Munro Kelly concept is that the intracranial cavity is

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a closed and rigid compartment with three components: They are brain (80%), blood (12%) and CSF (8%). Its total volume is 1600_ml, and that increase in any one of these components can be achieved only at the expense of another. Thus in the event of a growing mass lesion in the brain, the initial response would be a decrease in the volume of CSF and blood (mainly from the venous sinuses), and once this compensatory mechanism failed, the ICP would begin to rise significantly. This is the principle that underlies all the causes of raised ICP, most of which are multifactorial. The quest for developing the ideal method of recording ICP has been a difficult exercise. The first requirement for any method is that it is accurate; and it should also be safe and simple.[3] The search is still incomplete, since all current methods are invasive. The necessity to breach the skull to record ICP has resulted in a significant number of neurosurgeons being reluctant to embrace this technique. It took at least 15 years before ICP monitoring became fully accepted into clinical neurosurgical practice in more than a few centers. Even now, opinions vary as to the value of the technique, from those who claim that it makes no difference to the outcome of any neurosurgical disease to those who assert that it is an indispensable part of neurosurgical practice, without which many patients would surely die. The truth lies somewhere between these two extremes and it depends on the facilities and personnel available in any given neurosurgical unit.[4]

MEASUREMENT OF ICP

Historical aspects

1. Lumbar Puncture: Lumbar puncture was introduced into clinical medicine in 1897[5] and following this, the spinal CSF pressure was used as an indirect measure of ICP. Sharpe published a monograph on head injury in 1920 and stated that his principal indication for the operation of sub temporal decompression was a spinal fluid pressure above 15mmHg.[6] Jackson also advocated the use of lumbar puncture and pressure measurement in head injury in 1922,[7] but there was much disagreement on the place and dangers of lumbar puncture, and the reliability of the procedure in accuratelymeasuring ICP. The two principal objections to lumbar puncture in the diagnosis of intracranial hypertension have been the danger of inducing brain-stem compression through tentorial or tonsillar herniation and the contention that spinal fluid pressure is not always an accurate reflection of ICP. Langfitt's work was particularly important in demonstrating this lack of correlation between ICP and spinal CSF pressure under conditions of high ICP.[8]

2. Ventricular puncture: Ventricular puncture for the relief of increased ICP is one of the oldest practices in neurosurgery. Pressure measurements during this procedure were often done but prolonged pressure measurements were performed infrequently because water and mercury manometers were cumbersome and also because of the risk of intracranial infection.

Current aspect: The development of strain gauges allowed ICP measurement to be performed directly using a ventricular catheter and an external transducer. The pioneering neurosurgeons in its development were Janny and Lundberg (1960). Since then, the technique has been widely adopted, with some variations. There are other several techniques available for monitoring that vary in accuracy, ease of use and cost. These have been ranked by the Brain Trauma Foundation[2] based on their accuracy, stability and ability to drain CSF as follows:

- Intraventricular devices - fluid-coupled catheter with an external strain gauge or catheter tip pressure transducer
- Parenchymal catheter tip pressure transducer devices
- Subdural devices - catheter tip pressure transducer or fluid-coupled catheter with an external strain gauge
- Subarachnoid fluid-coupled device with an external strain gauge
- Epidural devices

Transducers: Transducers for measuring pressure are based on strain gauges, which were originally developed by Engineers and were able to measure the effects of tension and compression in beams. The applied force (per unit area) is called the stress and the resulting increase in length (per unit length) is called the strain. The operation of a wire strain gauge depends on the fact that if a length of wire is stretched, its electrical resistance will increase, and vice versa.

In a commonly used transducer such as the Statham P23 series, four strain-sensitive wires are connected to two frames, one of which fits inside the other. The wire frame is attached to the diaphragm of the transducer (upon which the pressure acts) and the outer frame is fixed. The set of wires form a Wheatstone bridge network, which is energized by a direct current. A stable DC amplifier is used to detect the imbalance of the DC bridge, and this signal can then be used to drive a pen recorder or be displayed on an oscilloscope. It goes without saying that the staff in an intensive care unit must be familiar with calibrating and maintaining pen recorders.

Catheter-tip transducer: Catheter-tip transducers have been used for several years and this is currently the preferred method of recording ICP. Miniature implantable transducers have been developed from intravascular transducers, of which the Camino transducer is an example. Pressure is measured at the tip of a narrow fiberoptic catheter where there is a flexible diaphragm. Light is reflected off the diaphragm and these changes in light intensity are interpreted in erms of pressure. The outside diameter of the device is only 4 FG (1.3mm). The system is not dependent on a fluid column, or on an external transducer where the height needs constant readjustment depending on the level of the patient's head. Ostrup and Crutchfield have reported excellent results but cost is still a problem.[9,10] There is a close correlation between ICP measured by the Camino catheter-tip transducer and the intraventricular method.[11] The Inner space transducer is a similar type of a fiberoptic catheter-tip transducer, but the physical principle uses spectral frequency. Marmarou has reported both experimental tests on this transducer.[12,13] The main limitation of a catheter-tip transducer is that it is not possible to calibrate it in situ and it should be replaced if monitoring is to be continued for longer than 5 days, because of possible drift. They are simple to insert and we place the tip in the brain at a depth of 1–2cm. The fiberoptic cable can be damaged by restless patients or if it is bent acutely, and this fragility is a practical problem and is one that limits the usefulness of the method.

Implanted microchip transducer: Implanted microchip sensors have now been developed and an example is the Codman Micro Sensor transducer. It consists of a miniature solid state pressure sensor mounted in a very small titanium case (diameter 1.2 mm = 3.6 FG) at the tip of a 100 cm long flexible nylon tube (diameter 0.7mm 2.1FG). The transducer tip contains a silicon microchip with diffused piezoresistive strain gauges which are connected by wires in the nylon tube to complete a Wheatstone bridge type circuit. When the transducer is energized and pressure is applied, the silicon diaphragm deflects a small amount (less than 0.001mm3 for 100mmHg applied pressure), inducing strain in the embedded piezoresistors. This resistance change is reflected in the form of a differential voltage which is then converted into units of pressure, i.e millimeters of mercury. The bottom layer of the silicon diaphragm is vented to the atmosphere along the nylon tube, while the top layer is exposed to the applied CSF or brain tissue pressure. The microsensor transducer can be inserted directly into the brain parenchyma but is also fine enough to be passed through a catheter into the lateral ventricle. Narayan and his colleagues found that this device had an average drift of less than 1mmHg over a 9-day period.[14] This group also tested the Codman transducer in 25 patients, comparing it against a ventricular catheter and an external transducer.[15] Encouragingly low levels of baseline drift were found and it showed no tendency to under-read or over-read. Piper and Miller evaluated the waveform analysis capability of this transducer against a fluid coupled transducer.[16] They found that there were no significant differences between the two transducers. Actually the microchip transducer has a superior frequency response, although this may not be clinically important for wave form analysis.A variation of a ventricular catheter with a pressure measuring transducer located at the tip of the catheter is the Ventcontrol MTC.[17] This technology represents the direction in which ICP monitoring will evolve. It is not easy to decide which system of ICP measurement is the best, because of the large number of Variables, including cost. If access to the ventricle is required, then a ventricular catheter and external transducer is both cost-effective and reliable; it is the 'gold standard'. However, most patients now being monitored for ICP are likely to be suffering from head injury and they will usually have narrow ventricles, making cannulation potentially difficult for a young neurosurgeon. In the head-injury situation, the preferred method is either a fiberoptic catheter-tip transducer (e.g. Camino or InnerSpace) or an implantable transducer (e.g. Codman) inserted into brain parenchyma, and this can be done at the bedside very simply. The choice between these two types of transducer largely comes down to a question of cost, which varies from country to country and is a individual decision.

Intraventricular pressure recording: The methodology for measuring ICP has evolved progressively, with many workers preferring a fluid coupled system using a ventricular catheter and an external transducer, considering it to be the 'gold standard' of ICP measurement.[18] Ventricular ICP recording is the most reliable method in current use and it has the advantage of minimal expense and maximal accuracy, since the external transducer can be calibrated against an external reference at any time. The equipment required is commonplace in any intensive care unit. The reference point for an external transducer should be the foramen of Monro, because it is close to the center of the head – 2 cm above the pterion, is a rough guide to its surface marking. The midpoint of a line joining the two external auditory meatus is another suitable reference point, although somewhat posterior to the interventricular foramen. Other workers use the external auditory meatus.[19] Whatever reference point is used, the level of an external transducer needs to be altered with each change in head position. The ventricular method obviously requires placement of a catheter into a lateral ventricle, and this may be a technically difficult procedure because of a narrow or displaced ventricle. Injury of the basal ganglia can occur with ill directed or over enthusiastic attempts at ventricular cannulation. The infection rate is 3.6%, reaching a potentially serious level after three days.[3] Other quoted infection rates range from less than one percent to more than 5%.[20] A big advantage of the ventricular method is that CSF can be withdrawn to lower ICP. All joints in the recording system must be watertight. If they are not, 'micro-leaks' will invalidate the pressure recordings. Each portion of the system must be tested periodically by isolating the external system from the patient temporarily and subjecting it to a pressure head of about 50mmHg. After being isolated, the external system should maintain its intraluminal pressure and if not, the connections must be tightened or the system discarded and replaced with a watertight system.[21] Sometimes, ventricular catheters block and this can be overcome by flushing a small amount of sterile saline through the system. However, repeated flushing should be avoided because of the real risk of infection.

Other Methods: The hollow skull bolt ('Richmond screw') has been widely used in many centers.[22] There have been many modifications to achieve a lower profile, CT compatibility, more side holes ('Leeds screw'), and a pediatric version.[2,23-25] These devices are simple to insert but they have a tendency to block and so produce a damped, inaccurate trace. At high pressures, the subdural bolt tends to read lower than a ventricular catheter.[26,27] This question of accuracy presents a major problem and is the main reason why the hollow bolt method has declined in popularity.[4] Subdural catheters can be useful where the ventricle cannot be Cannulated, but they are also likely to underestimate the true ICP. The extradural site for monitoring has been used and has the advantage avoiding penetration of the dura. However, there are technical problems associated with the inelasticity of the dura and the need for the transducer to lie flat (co-planar) on the dura. Unfortunately, irregularities of the dura and inner table of the skull are common. If co-planarity is not achieved, stresses and strains in the dura can distort the measurements and falsely record high pressure.[2,28] For these reasons concerning accuracy, the extradural method is now used very infrequently.

Is ICP monitoring useful? The continuous measurement of ICP is an essential modality in most brain monitoring systems. After a decade of enthusiastic attempts to introduce new modalities for brain monitoring (tissue oxygenation, microdialysis, cortical blood flow, transcranial Doppler ultrasonography, jugular bulb oxygen saturation) it is increasing obvious that ICP is robust, only moderately invasive, and can be realistically conducted in regional hospitals. Although there has been no randomized controlled trial about influence of ICP monitoring on overall outcome after following head injury, recent audit[5] shows almost twofold lower mortality in neurosurgical centres, where ICP is usually monitored, versus general intensive care units, where it is not monitored. However, the availability of ICP monitoring is not the only difference between neurosurgical and general intensive care units that might explain the difference in mortality after head injury. ICP waveform contains valuable information about the nature of cerebrospinal pathophysiology. Autoregulation of cerebral blood flow and compliance of cerebrospinal system are both expressed in ICP. Methods of waveform analysis are useful both to derive this information and to guide the management of patients. The value of ICP in acute states such as head injury, poor grade subarachnoid hemorrhage, and intracerebral haematoma depends on a close link between monitoring and therapy. CPP oriented protocols,[20,29] osmotherapy[2] and the "Lund protocol" cannot be conducted correctly without ICP guidance. A decision about decompressive craniectomy should be supported by the close inspection of the trend of ICP and, preferably, by information derived from its waveform.[30] In encephalitis,[31] acute liver failure[24] and cerebral infarction after stroke,[32] ICP monitoring is used less commonly, however, an increasing number of reports highlight its importance. A slightly different methodology for CSF pressure interpretation is applied in chronic states such as hydrocephalus or benign intracranial hypertension. In the first case assessment of CSF, pressure–volume compensation and circulation are essential to optimize patient management.[33] Volume-adding tests with parallel measurement of ICP and/or overnight ICP monitoring with waveform analysis have a special role. In patients with a shunt in situ, who present with persistent or recurring clinical symptoms, it helps to avoid unnecessary shunt revisions.

This is particularly important as patients with a history of multiple shunt revision have a lower chance to achieve good outcome in the future. In benign intracranial hypertension[34] or craniostenosis[35] ICP monitoring has been documented as useful both for diagnosis and to document response to therapy.

Complications of ICP monitoring: The potential complications of ICP monitoring include malposition, malfunction, infection and hemorrhage. The incidence of each of these varies with the type of monitoring being done and the experience of the personnel performing the monitoring.

Malposition: This is most commonly seen with intraventricular devices, where the catheter either misses the ventricle or is inserted too far into the ventricle. The subarachnoid bolt will under-read ICP if the dura is not properly opened, and similarly all other devices have their own need for a correct technique of insertion.

Malfunction: This is the common complication, occurring in different ways for different types of monitors. If too much CSF is drained, the ventricles collapse around the intraventricular catheters and they are blocked. Parenchymal catheters had a major problem of drifting zero point and they cannot be re-zeroed like the ventricular catheters, resulting in greater inaccuracy with length of monitoring.

Infection: Infection in relation to ICP monitoring generally refers to a positive culture of CSF or the device, and reported infection rates vary widely and with the type of device. Intraventricular device infections range from 0% to 10.5%. There is a general consensus that the duration of monitoring has a direct relationship to incidence of infections and that the infection rate climbs steeply after 5 days, though this can be mitigated by subcutaneous tunneling of the device.

Hemorrhage: The limited published reports of hemorrhage rate also vary, with an average incidence of 1.1% reported for intraventricular devices. The incidence is approximately 2.8% for parenchymal devices.

CONCLUSION

ICP monitoring is developed as a very useful tool, Particularly in patients suffering from head injury. If a decision is made to monitor ICP, then certain standards must be achieved so that reliance can be placed on the data, which are obtained. Other physiological Variables such as arterial BP are also recorded whenever possible. The catheter-tip and implanted microchip transducers as having replaced the ventricular catheter and external transducer as the 'gold standard' in ICP measurement. ICP monitoring provides the only sure way of confirming or excluding intracranial hypertension.

ICP monitoring provides the only reliable method of assessing whether therapy will work and provide an early opportunity of switching to an alternative therapy. If increased ICP is not present, potentially dangerous treatment can be avoided. If the patient is paralyzed or heavily sedated, conventional neurological observation is useless and ICP monitoring provides a means of determining the patient's cerebral perfusion pressure (CPP) and an index of cerebral function.

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