Critical Care Technology: Intracranial Pressure and Brain Tissue Oxygenation Monitoring

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“I pledge on my honor that I have neither given nor received inappropriate aid on this assignment.”

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Abstract

Remarkable advances have been made in critical care technology over the past decade. The topic that will be discussed in this paper focuses on equipment specifically used to monitor and treat patients that suffer from traumatic brain injury (TBI) such as aneurysmal rupture and subarachnoid hemorrhage (SAH). This technology includes monitoring devices for intracranial pressure (ICP) and brain tissue oxygenation. There are ICP monitoring devices, such as ventriculostomies, that also contain drainage systems for cerebrospinal fluid (CSF). In order to successfully assess and monitor the progress of treatment in patients with TBI, several neurological parameters must be determined such as ICP, mean arterial pressure (MAP), cerebral perfusion pressure (CPP), partial brain tissue oxygenation (PbtO₂), and jugular venous oxygenation saturation (SjvO₂). This paper will examine several devices for measuring treatment and outcomes in patients with TBI, three research articles regarding the use of different methods of measuring patient progress in terms of ICP and cerebral perfusion, and the nurses role in assessing and caring for these patients.

Keywords: traumatic brain injury, subarachnoid hemorrhage, intracranial pressure, ventriculostomy, cerebral spinal fluid, mean arterial pressure, cerebral perfusion pressure, PbtO₂, SjvO₂
Critical Care Technology: Intracranial Pressure and Brain Tissue Oxygenation Monitoring

The topic that will be discussed in this paper is the use of intracranial pressure monitoring along with brain tissue oxygenation measurement in patients suffering from acute and traumatic brain injury. Intracranial pressure monitoring does exactly what the name suggests; it measures the pressure within the skull. Monitoring patients ICP is significant because an increased ICP can increase the risk of brain ischemia and infarction due to a diminishing cerebral perfusion pressure. Increased ICP also can be associated with poor patient prognosis and serves as a valuable indicator to guide patient treatment. A normal ICP is between 5-15 mm Hg and any values sustained above 20 mm Hg are abnormal and require further investigation and treatment (Lewis, Dirksen, Heitkemper, & Bucher, 2014). Increased intracranial pressure can be caused by a mass such as a hematoma, tumor, or abscess or by cerebral edema associated with hydrocephalus or other head injury (Lewis et al., 2014). Cerebral perfusion pressure is an indication of brain tissue oxygenation. The normal range for CPP is between 60-100 mm Hg. CPP values less than 50 mm Hg suggest ischemia and neuronal death and values less than 30 mm Hg are incompatible with life (Lewis et al., 2014).

My reason for choosing this particular topic is to become more familiar with the interventions and theories that guide the care for patients who suffer from traumatic brain injury. In the future I hope to become a critical nurse, particularly working with neurologic patients. My interest in this topic was sparked by the unfortunate passing of my wonderful and loving mother, in February of 2013 to a ruptured cerebral aneurysm and subarachnoid hemorrhage. She was admitted to Hackensack’s surgical intensive care unit on February 8th and passed away on the 25th. I spent those seventeen days on the unit picking the brains of all the nurses, residents and
attending neurosurgeons I could find. The careful and easy to understand explanations that I received from my mother’s nurses and neurosurgeons were not always comforting but they helped me understand what was going on and I used that to try and accept the situation I was faced with. Each day, at least one person on the team would sit down with me and explain the course of events, which included a high risk of vasospasm and stroke as well as a risk for a recurrent bleed. Endovascular coiling was the first surgical intervention performed and one of the last performed was a craniectomy. The vasospasms did occur within the seventeen days and unfortunately so did several strokes. My family and I were grateful to have such a caring team working on the most important person in our lives. I chose this topic because I now have an understanding of both sides, the patient and family as well as the nurse and healthcare worker. I hope that one day in the future I can provide patients suffering from traumatic brain injury and their families with the support, expertise, and kindness that I received.

Intracranial pressure can be measured by the use of three different methods. The first method is a ventriculostomy. A ventriculostomy consists of a specialized catheter that is inserted into the ventricle of the brain and an external transducer. A ventriculostomy has three significant functions that help to guide practice; it measures the pressure directly from the inside of the ventricles, allows removal and sampling of cerebrospinal fluid (CSF), and allows for intraventricular administration of drugs (Lewis et al., 2014). The concept of a ventriculostomy is similar to that of hemodynamic monitoring of the cardiac and pulmonary system; the transducer of the ventriculostomy must be at the same level as the foramen of Monro. The reference point used for the foramen of Monro is the tragus of the ear. It is imperative that the transducer is assessed and leveled every time the patient is repositioned (Lewis et al., 2014). The second
method used is a fiberoptic catheter that has a sensor transducer located within the catheter tip, which is placed directly into the ventricle or brain tissue for pressure measurement. The third method used is a subarachnoid bolt/screw. This method is usually used for patients with mild head injury and does not allow drainage of CSF, but offers the availability of easily being converted into a ventriculostomy if the patient’s condition starts to deteriorate (Lewis et al., 2014). The subarachnoid bolt is placed through the skull and between the arachnoid membrane and cerebral cortex (Lewis et al., 2014).

If a ventriculostomy is the chosen method for intracranial pressure monitoring, it is important to understand how it works, how to measure ICP, what the normal range is, how to interpret different measurements, and how to read waveforms. ICP should always be measured as a mean pressure and in order to obtain an accurate measurement of ICP, the drainage system must be closed for a minimum of six minutes to ensure a correct value (Lewis et al., 2014). A normal ICP waveform consists of three phases and should be assessed and documented frequently. The normal waveform resembles a staircase of P1, P2, and P3. P1 is the percussion wave that represents the arterial pulsations and is normally the highest waveform; P2 is the rebound wave that reflects brain volume and compliance, if this waveform rises higher than P1 it signifies that ventricular compliance has been compromised; P3 is the dicrotic wave that represents venous pulsations and is the lowest of the waveforms (Lewis et al., 2014). Inaccurate ICP readings may be obtained if readings and patient presentation are not thoroughly assessed. Several factors can cause inaccurate readings such as obstruction of the catheter from a blood clot, a difference in the level of the catheter and the transducer, cerebrospinal fluid leaks around the device, and kinks or air in the tubing (Lewis et al., 2014).
A ventriculostomy system also has the ability to remove cerebrospinal fluid to help control and stabilize the ICP. A physician order is needed to initiate any kind of drainage and the order will indicate at which value to open the drainage system. When ICP is greater than the ordered level, the nurse is to open the stopcock and allow intermittent or continuous drainage. If intermittent drainage is ordered, the ventriculostomy drainage system is opened for about three minutes and then returned to a closed system (Lewis et al., 2014). If continuous drainage is ordered, the nurse must carefully monitor the volume of CSF that is being drained and the stopcock is kept open (Lewis et al., 2014). The patient with intracranial pressure monitoring requires frequent, vigilant, and expert nursing assessment. It is important to let anyone who will be with the patient or provide care to the patient that they are to notify the nurse before turning, moving, or suctioning the patient (Lewis et al., 2014). A sign is usually placed above the bed to remind anyone who enters the patient’s room about the importance of notifying the nurse first.

Cerebral oxygenation monitoring is essential for the client with traumatic brain injury. This type of monitoring measures perfusion and brain oxygenation. There are two different monitoring devices that will be discussed. The first device is called a LICOX catheter and this measures oxygenation of the brain as well as internal temperature. This catheter is placed into the white matter of the brain and continuously monitors the pressure of oxygen in brain tissue (PbtO$_2$); the normal PbtO$_2$ range is between 20-40 mm Hg and lower levels are indicative of ischemia (Lewis et al., 2014). The second device is called a Jugular venous bulb catheter and this catheter is placed in the internal jugular vein with the catheter tip positioned in the jugular bulb as the name suggests. This device provides measurements of jugular venous oxygenation saturation (SjvO$_2$); the normal SjvO$_2$ range is between 55%-75% (Lewis et al., 2014). After
insertion of invasive monitoring devices, it is important to verify their placement with an x-ray. The goal for these patients is to maintain a \( \text{PaO}_2 \) of 100 mm Hg or greater and to keep \( \text{PaCO}_2 \) in the normal range between 35-45 mm Hg (Lewis et al., 2014).

All of the monitoring devices mentioned thus far are invasive and tend to have a list of potential complications. Infection is a common and major complication. Patients are at higher risk for infection if they have intracranial pressure monitoring for more than five days, have a ventriculostomy, have a cerebrospinal fluid leak or a concurrent systemic infection (Lewis et al., 2014). In order to prevent infection, the nurse is responsible for routinely assessing the insertion site, maintaining strict aseptic technique when providing direct care to the catheter and obtaining samples, and to monitor the amount, color, clarity and any changes in the drained cerebrospinal fluid (Lewis et al., 2014). Other complications include ventricular collapse, herniation, and subdural hematoma formation from rapid decompression (Lewis et al., 2014).

The critical care nurse must understand the equipment and be educated on proper use and evaluation. Some examples include, the nurse is able to demonstrate the proper procedure for priming drainage tubing, maintaining sterility, attaching a syringe to the distal portion of the patient line, maintaining a closed system with the stopcock in the off position, zeroing and referencing the system, and maintaining the pressure that is ordered for the patient (Slazinski et al., 2011). The nurse is also responsible for assessing the patient’s vital signs before, during, and after insertion of the catheter and drainage system (Slazinski et al., 2011).

Important elements of nursing care for clients with intracranial pressure monitoring and drainage devices include but are not limited to the nursing process. Assessment includes that of the patient, family of the patient, monitoring and drainage devices, and the patient’s
environment. The patient assessment includes monitoring changes in ICP and associated signs and symptoms, level of consciousness, Glasgow coma scale score, patient position and reference level of the transducer and hourly neurological assessments (Slazinski et al., 2011). Hourly assessment should also include evaluation and documentation of the patient’s ICP and the color, amount, and clarity of the cerebrospinal fluid (CSF) drainage (Slazinski et al., 2011). Assessment of the ICP or external ventricular drainage system should be done a minimum of every four hours and should consist of inspecting the insertion site, the tubing, the drainage system and monitors (Slazinski et al., 2011). Special attention should be directed towards assessing the patient’s ICP waveform and being vigilant of any changes (Slazinski et al., 2011). Nursing diagnoses are made based on actual medical diagnoses, problems the patient has that can be fixed by nursing interventions and potential complications. Plans and interventions are based on the nursing assessment and physician orders for the patient assignment. Evaluation is performed and documented consistently to determine if interventions are successful.

Incorporating professional standards into nursing practice is of extreme importance. Each institution may have a different set of professional standards that they expect their staff to follow and practice by. Many nursing interventions differ from institution to institution and it is the nurse’s job to follow the set standards of the institution that he or she is working at. Professional standards provide uniform throughout hospital staff and maintaining these standards put patients and patient families at ease by stating what is and what is not acceptable. Professional standards hold the healthcare workers and the institution to a higher degree.

Nursing care and interventions are guided by professional nursing standards and evidence based practice. There are three evidence based nursing articles that will be summarized and
evaluated about intracranial pressure monitoring and patients suffering from traumatic brain injury. The first article, “An observation pilot study of CSF diversion in subarachnoid haemorrhage,” focuses on preventing cerebral artery vasospasms following a subarachnoid hemorrhage (SAH). The aim of this article is to compare the different methods of CSF drainage and intracranial pressure monitoring with the outcomes of patients diagnosed with SAH. The article states that a subarachnoid hemorrhage occurs from a ruptured cerebral aneurysm and following the hemorrhage there is a high occurrence of vasospasms from day four to day twelve (Amato et al., 2011). The treatment of SAH is guided and determined by several different factors. First, the severity of the SAH needs to be assessed and graded. Grading the severity can be done by using either the “Hunt and Hess” score or the “Fisher grade”. According to this article, the Fisher scores correlate with high incidence of cerebral vasospasm (Amato et al., 2011). Treatment of SAH involves pharmacological management such as osmotic diuretics, anticonvulsants, calcium channel blockers and surgical treatment with either a clip ligation of the aneurysm or endovascular coiling which encourages clot formation. The treatment of choice is going to rely on the location, severity, and type of aneurysm. Determination that a patient will need intracranial pressure monitoring is based on if they have an abnormal brain CT scan, suffered a neurological insult, or has a Glasgow Coma scale score of eight or less (Amato et al., 2011).

The nursing care of patients at risk for or suffering from vasospasm and stroke involves monitoring neurologic functioning, ICP, arterial blood gases and blood pressure. The neurologic monitoring includes managing intracranial pressure and CSF drainage. The importance of monitoring ICP is emphasized based on the knowledge that increased ICP provides important
information about patient status and whether the patient is improving, remaining the same, steadily declining or rapidly deteriorating. In this study, nursing interventions were aimed at maintaining cerebral perfusion, promoting venous drainage by keeping the head of the bed at thirty degrees, reducing patient pain and anxiety, assessing and documenting intake and output, educating the patient and family, and continuously advocating for the patient and the patient’s rights (Amato et al., 2011).

In order to prevent and manage these vasospasms, cerebral blood flow and cerebral perfusion pressure must be maintained. During the period of four to twelve days after a SAH, an external ventricular drainage (EVD) monitoring system is inserted to monitor ICP and in some cases, with a physicians order, facilitate the drainage of cerebrospinal fluid. Although monitoring ICP is imperative, there are several complications associated with it such as infection, hemorrhage, malfunction and possible obstruction. It is the nurse’s duty to be vigilant and monitor for complications and intervene as quickly as possible.

This particular study explored two interventions and compared the separate results to determine which one was associated with a greater reduction in ICP. The two interventions used were separated into two different groups, one consisted of patients with continuous CSF drainage with intermittent ICP monitoring and the second consisted of patients with near continuous ICP monitoring and CSF drainage that occurred only then the ICP values exceeded the ordered threshold. The intermittent method allowed the nurse to continuously monitor the patient’s ICP while the external ventricular drainage system was closed. The method that involved continuous CSF draining did not allow frequent monitoring of the patient’s ICP because accurate ICP values cannot be obtained if the system and stopcock remain open.
The overall findings of this study were reported to not be significant enough to provide proof that one intervention was better than the other because of the small scale of comparison with participating patients (Amato et al., 2011). However, the study did show that there was evidence that there were more complications associated with the continuous CSF open external ventricular drainage system. The continuously open drainage system does not allow for frequent monitoring of the patient’s ICP, which is a necessary value that guides patient treatment (Amato et al., 2011). Although an intermittent drainage system requires more of the nurses time and resources requiring him or her to frequently enter the patients room and manipulate the ventricular drainage system, it provides for more frequent ICP monitoring and accurate values which lead to safer and more efficient patient care (Amato et al., 2011).

The second article, “Reviewing the reliability, effectiveness and applications of Licox in traumatic brain injury,” summarizes the multiple treatments performed on patients with TBI that were successful due to the Licox monitoring system. There have been improved outcomes in patient management with TBI while using the Licox monitoring system (Keddie & Rohman, 2012). “The Licox monitoring system consists of three sensors being placed through a bolt into the white matter of the brain allowing continuous monitoring of partial pressure of brain tissue oxygen (PbO₂), brain tissue temperature and intracranial pressure (Keddie & Rohman, 2012).” It is so important that critical care units have equipment and monitoring systems such as the Licox for patients that suffer from traumatic brain injury. The primary insult of brain injury almost always has a secondary injury. This secondary injury is caused by the body’s response to the primary insult by releasing mediators for inflammation, cerebral vasoconstriction and edema, which raise the intracranial pressure (Keddie & Rohman, 2012). The increase in intracranial
pressure is the factor that reduces cerebral perfusion pressure, thus brain ischemia and infarction can occur (Keddie & Rohman, 2012). Although it is stated that increases in ICP and decreases in CPP lead to ischemia and infarction, this article includes research from studies that demonstrated cerebral infarction that has occurred in patients that did not have changes in ICP and CPP.

The Licox proved its importance by allowing clinical specialists to maintain and monitor cerebral oxygen saturation with changes to MAP, ICP, CPP, and CBF (Keddie & Rohman, 2012). This means, secondary brain injury can potentially be prevented by identifying cerebral hypoxia earlier and treatment can be implemented to improve the cerebral perfusion pressure (Keddie & Rohman, 2012). Licox also helps clinicians monitor cerebral oxygenation during cardiopulmonary resuscitation (CPR). This is particularly important during prolonged CPR to determine patient prognosis, if the CPR is effective or if increased efforts are needed to overcome ischemia, and whether CPR should be withdrawn or not (Keddie & Rohman, 2012). Licox monitoring system provides continuous monitoring of PbO$_2$ and records the duration and number of hypoxic episodes, which is extremely valuable in prevention. Licox is important in prevention because it has the ability to detect subtle cerebral hypoxia even if the intracranial pressure is normal (Keddie & Rohman, 2012). Treatment can now be evaluated for it’s effectiveness and implemented earlier with the use of Licox monitoring. Licox monitoring is used with several treatment interventions such as, improving the CPP by decreasing the ICP or increasing the MAP, increasing FiO$_2$ before suctioning patients suffering from a traumatic brain injury, lowering the PbO$_2$ threshold by inducing hypothermia, guiding the level of hyperventilation used in patients with intracranial hypertension, elevating the head of the bed.
thirty degrees, and in the pharmacological use of nimodipine and mannitol (Keddie & Rohman, 2012).

There are numerous benefits to clinical practice regarding the use of Licox monitoring. However, the emphasized indications in this monitoring system are its ability to detect subtle cerebral hypoxia, offers pathophysiologic information that allows specialists to change treatments, offers data than can be interpreted at the patients bedside, and has been demonstrated to be accurate, reliable and safe to use in the clinical setting (Keddie & Rohman, 2012).

The third article, “Arterial transducer placement and cerebral perfusion pressure monitoring: a discussion,” emphasizes the importance of educating and training critical care nurses about TBI and the different monitoring systems. It stresses the importance of accurate calibration and how inaccurate calibration and failure to notice inaccurate calibration will lead to inappropriate treatment. This article also pointed out that there are many different practices in critical care units when it comes to measuring CPP and TBI outcomes. There is a great emphasis on the need for standard methods for monitoring throughout all critical care units worldwide (Jones, 2009).

Literature about two different reference points for accurate arterial transducer placement were examined and researched in this article. Positioning the transducer at the level of the external auditory meatus was the first reference point researched and the second reference point was the mid axilla. Research showed that placing the transducer at the level of the external auditory meatus recorded a MAP value lower than the MAP value recorded when the transducer was positioned at the level of the mid axilla (Jones, 2009). The lower MAP associated with transducer placement at the external auditory meatus had a lower cerebral perfusion pressure
value and the higher MAP associated with transducer placement at the mid axilla had a higher CPP value. The reason the difference of the values associated with each transducer placement is so important is because a different CPP reading will determine a different treatment plan. This article expresses a significant clinical dilemma in terms of managing patients with TBI; it states that is the transducer was placed at the external auditory meatus with a lower CPP value, the CPP may be underestimated and could lead to unnecessary or detrimental administration of vasopressors and fluids which can cause cerebral edema (Jones, 2009). If the transducer is placed at the mid axilla with a higher CPP value, the CPP can be over estimated and exposes the patient to potential cerebral ischemia (Jones, 2009).

Although this article, which was written in 2009, states that it found no conclusive evidence in it’s research as to which reference point for the arterial transducer is the correct one, the Medical-Surgical Nursing textbook written by Lewis et al. (2014) when speaking about a ventriculostomy states, “A reference point for this foramen is the tragus of the ear (Lewis et al., 2014).” The research does not provide a definitive reference point for nursing intervention and treatment but it does stress the importance of a worldwide critical care standard for monitoring cerebral perfusion pressures. If emphasizes the importance of safe clinical practice and being aware of the position of the transducer because it’s values determine the treatment that will follow. This article informs nurses how critically important it is to be vigilant at all times in their assessments with critical care patients and patients with traumatic brain injury.

Safety and prevention are the major concerns in the healthcare industry. Being that there is such a wide variety of technology available in healthcare today, it is important to keep nurses, physicians and technicians educated in using and troubleshooting this technology. Safety
concerns related to the use of intracranial pressure monitoring and drainage systems are mainly focused on infection and malfunction, both of which can be prevented by ongoing education and consistent assessments. Safety can be maintained by continuously assessing and documenting about both the patient and the monitoring device, maintaining sterility when changing the patient’s dressing and when obtaining samples of CSF, and meticulous hand washing (Slazinski et al., 2011). The monitoring device must be assessed starting at the patient’s insertion site and moving in the direction toward the device. The waveforms must be assessed and the nurse is responsible for reading them and detecting and documenting changes. Troubleshooting the equipment is important as well, if patient readings do not seem to be right or if malfunction is suspected, the nurse is expected to be able to calibrate the device, zero the system and level the transducer with the appropriate reference point (Slazinski et al., 2011). The nursing responsibilities and interventions that follow placement of ICP monitoring and EVD devices include assisting the physician in connecting the catheters to the monitors and maintaining sterility in the process (Slazinski et al., 2011), applying a sterile dressing to the insertion site, monitoring the ICP, assessing the patient’s tolerance to the insertion of the device, obtaining vital signs, administering any ordered medications, and proper disposal of instruments and equipment (Slazinski et al., 2011). Documentation was also mentioned several times; this is because the importance of documentation is so great. If you did not document it, you did not do it.
References


