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Management of External Ventricular Drains During Intrahospital Transport for Radiographic Imaging

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A B S T R A C T

Critically ill patients with brain injury often need intracranial pressure (ICP) monitoring. The two most common methods of ICP monitoring are via an external ventricular drain (EVD) catheter and via an intraparenchymal fiberoptic catheter. In addition to ICP monitoring, an EVD has the additional advantage of being able to treat hydrocephalus or lower elevated ICP by cerebrospinal fluid drainage. In addition to ICP monitoring, frequent radiographic imaging is also considered to be a fundamental component of neurological multimodal monitoring. As such, patients with EVDs often require intrahospital transport for advanced imaging. There are currently no national or international standards guiding intrahospital transport to and from the radiology suite. We use a fictional case to describe practice patterns and variations that may improve care of the patient with EVDs during transport to radiology. The fundamentals for ICP monitoring are highlighted, and an emphasis is placed on clear and concise communication.

Introduction

Computerized tomography (CT) of the head and intracranial pressure (ICP) monitoring are an inevitable pairing (Bergman et al., 2017). From the moment the first CT was performed, it was clear that neuroimaging would become a mainstay of providing care for neurologically injured patients. Coincidentally, ICP monitoring also took off at about the same time. Despite advances in portable imaging technology, most patients with ICP monitors are transported from intensive care unit (ICU) settings to imaging centers. The purpose of this article is to provide an understanding of common ICP-monitoring devices and outline of the proper techniques to ensure safe transport and imaging for patients with an external ventricular drain (EVD) for ICP monitoring.

Background and significance

The importance of ICP monitoring has been long recognized. The first steps were taken in the 1800s when Francois Magendie described cerebrospinal fluid (CSF) pathways (Andrews and Citerio, 2004). In 1891, Quinke published his method of measuring CSF pressure through a lumbar puncture (Benveniste et al., 2015). This practice was widely accepted; however, this continued until it was linked to a high complication rate and it was found to not accurately reflect ICP (Andrews and Citerio, 2004). Later, Lundberg (Lundberg, 1960) used a fluid-filled catheter inserted into the lateral ventricle of the brain, which provided a continuous ICP recording. The use of an EVD described by Lundberg is now widely accepted as a standard of practice for ICP monitoring.

In 1895, Rontgen's research gave rise to X-ray and diagnostic imaging. Roughly a century later, Hounsfield invented the computed axial tomography scan, later shortened to CT. The first commercially available CT scanners were placed into service in 1973 at Massachusetts General Hospital and Mayo Clinic (Wijdicks, 2018), and within a few years, CT scanning was widespread at the national level. These images gave new insights into the neurologically compromised patient and revolutionized neurodiagnostics.

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Concurrently, ICP monitoring continued to gain traction within the medical community. Currently, a fiberoptic parenchymal catheter or an EVD is used to measure ICP (Olson et al., 2018). Some recent devices combine both technologies. The EVD is considered to be a standard for ICP monitoring. One of the many benefits of this device is that it can be used for both ICP monitoring and management. The ability to drain CSF allows for tight control of ICP and cerebral perfusion pressure (Livesay et al., 2017). In this review, we will discuss safe transport of a patient with an EVD.

Fundaments of intracranial pressure monitoring

There are three primary components to ICP monitoring by the EVD, namely, the drainage catheter (EVD), the external drainage management system (EDMS), and the transducer (Figure 1). The EVD is a hollow plastic catheter with multiple holes to facilitate the flow of blood and CSF out of the cerebral ventricles. The EDMS is a combination of hollow tubing, stopcocks, and a drainage-collection device. The pressure fluctuations within the ventricles are conducted through the fluid-filled catheter and tubing to the transducer. The transducer is a combination of a pressure-sensitive diaphragm and strain gauge used to convert mechanical pressure to an electrical signal by measuring changes in resistance. The ICP transducer is functionally similar to the arterial blood pressure transducer.

The EVD is placed under sterile conditions, either in the operating room or at the bedside, by a trained medical practitioner (Bazil and Olson, 2019). Initially, a small hole is drilled in the skull through which the catheter is passed. The tip of the catheter will typically terminate in one of the lateral ventricles or the third ventricle. Placement is verified by the presence of CSF draining from the catheter or by a CT scan. The catheter is then tunneled under the scalp to reduce the risk of infection.

After insertion, the catheter is connected to the EDMS tubing by a sterile technique. This tubing may have a combination of ports and stopcocks for the purpose of removing CSF samples. In rare and specific circumstances, the EVD can be used to introduce medications into the ventricular system (intrathecal medication administration). The distal stopcock is one of the most vital components of the EDMS. This is typically a 3-way stopcock that facilitates connection to an external transducer. Distal to the stopcock is a burette (used for measuring CSF volume) and a drainage-collection bag. The stopcock can be positioned to either allow ICP monitoring via the transducer or positioned to allow CSF drainage into the collection bag.

The external strain gauge transducer (often simply called the transducer) is connected to the EDMS as described previously but also is connected via cables to a bedside monitor. To accurately monitor ICP, the transducer must meet two conditions: (1) the transducer must be calibrated (zero-referenced or zeroed) to atmospheric pressure, and (2) the transducer must be leveled to a height that approximates the foramen of Monro within the skull. The process of zeroing the transducer requires the nurse to ensure that there is an unobstructed continuous column of fluid from the transducer to the external environment (air). The process of leveling requires that the nurse adjust the height of the EDMS and transducer to a point level with an external landmark (Malloy and March, 2016). An important point to note is that the EVD accurately measures ICP only when the stopcock is positioned to stop drainage and only allows connection of the EVD with the transducer (Samudra et al., 2018). If the stopcock is positioned to allow continuous drainage, the ICP value shown on the bedside monitor is not an accurate reflection of the patient's ICP. In such instances, the standard practice is to reposition the stopcock periodically (e.g., once an hour) to allow serial measurement of ICP.

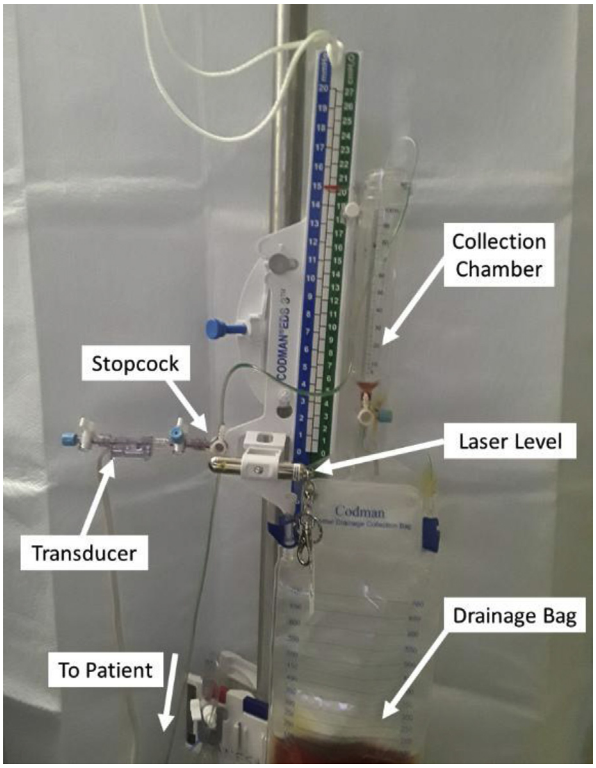

Figure 1. The external drainage management system with key parts labeled.

There is significant practice variation across the globe regarding best practice for EVD management and ICP monitoring (Olson et al., 2014). One area of discrepancy is the external landmark used to approximate the foramen of Monro (McNett et al., 2017). The most common reference points for the foramen of Monro are the tragus, of the ear, the external auditory meatus, and half-way mark between the outer canthus of the eye and the tip of the ear lobe. Another controversy stems around the position of the stopcock. The most recent worldwide practice survey found that 54.3% of practitioners preferred to position the stopcock to allow continuous drainage of CSF with intermittent ICP monitoring (Olson et al., 2014).

Fundaments of critical care transport

Intrahospital transport is inherently risky (Bergman et al., 2017). Most intrahospital transports involve patients with at least one threat or risk factor specific to the transport (Bergman et al., 2017). These include mechanical ventilation, continuous and intermittent intravenous (IV) sedation, the need for additional physiologic monitoring, and additional catheters and drains. For patients with critical illness or injury, intrahospital transport can significantly increase the risk for harm.

There are no universal standards to define parameters that show when the intrahospital transport begins or ends. Similarly, there are no universal standards of practice for intrahospital transport. For the purpose of this manuscript, the five stages of transport are defined as (1) preparation in anticipation of the transport, (2) transport to the procedure, (3) performing the procedure, (4) transport back to the patient's room, and (5) completion of a safety and monitoring assessment after transport.

Case presentations

The following is a case presentation of Miss Murphy, a fictional 49-year-old female. Her case is an amalgamation of various

Table 1
Key learning points for intrahospital transport of patients with an external ventricular drain

- Intracranial pressure (ICP) readings are accurate only when taken with the stopcock (open to the patient) and transducer (closed to drainage).
- Best practice is to keep the external drainage management system (EDMS) in a vertical position. Avoid laying the EDMS on the bed.
- If the external ventricular drain (EVD) is open, any elevation in table height or patient position may result in a sudden or excessive amount of cerebrospinal fluid (CSF) drainage.
- If excessive CSF drainage occurs, immediately clamp the EVD.
- Leaving the EVD open may place the patient at risk for entraining air into the ventricles if the table height or patient position is suddenly changed.
- Initiating and maintaining strong, closed-loop communication reduces errors and increases safety.
- Sharing responsibility allows each member of the team to perform their role and the intensive care unit nurse to focus their attention on the EVD and EDMS.
- Lowering the head of the bed may increase the volume of intracranial contents and ICP.
- Intrahospital transport begins and ends with a comprehensive patient assessment.

critically ill patients. This synthesized approach to case presentation is being used to facilitate incorporating a variety of key learning points (Table 1). This fictionalized case will be used to illustrate two radiographic procedures commonly performed for patients with ICP monitoring. The first transport is for a follow-up CT where everything goes as planned. The second transport is a worst-case scenario that details an emergency angiogram during which the radiology nurse (Rad-RN) encounters multiple complications.

Miss Murphy was admitted after a subarachnoid hemorrhage (SAH) from a ruptured anterior communicating artery aneurysm. She underwent successful aneurysm clipping on day 2 and was subsequently admitted to the ICU for monitoring. Although she was originally transferred with an artificial airway (endotracheal tube), she was quickly liberated from mechanical ventilation and was awake, alert, and oriented to person, place, time, and situation after surgery. The surgeon had placed an EVD positioned in her left lateral ventricle, with the stopcock closed to drainage, and orders to drain CSF if her ICP sustains at >15 mm Hg for >5 minutes. She has bilateral IV catheters in each arm.

Transport for follow-up CT scan

The neurosurgical chief resident orders a routine postoperative follow-up noncontrast CT scan of the head and a CT angiography with contrast to confirm placement of the EVD and to provide baseline imaging for later comparison.

Preparation in Anticipation of the Transport

The ICU nurse (ICU-RN) contacts the radiology team to confirm transport time. Before transport, the ICU-RN connects the patient to portable telemetry. The EDMS is hung on an IV pole with the transducer leveled to approximate the foramen of Monro. Because the nurse had earlier noted mild respiratory distress, Miss Murphy is transported to CT accompanied by the nurse, a respiratory therapist, and a transport tech.

Before transport, the ICU-RN conducts an assessment using the National Institutes of Health Stroke Scale (NIHSS) score to obtain a baseline for the patient. Miss Murphy has an NIHSS of 1 (minor right leg weakness). The nurse also agrees with the transport tech that the tech will be responsible for steering the bed while the nurse closely monitors the EVD and the patient's vital signs. There will be obstacles for the transport tech to avoid, and the nurse wants to ensure that nothing gets caught on the tubing of the EVD. If this happens, the EVD could accidentally dislodge.

Transport to the Procedure

When transporting the patient, the head of the bed (HOB) is positioned at a 30-degree angle and the patient's head is kept midline to increase cerebral perfusion. This will also decrease the risk of a spike in the ICP throughout the transport (Altun Ugras et al., 2018). Upon arrival, the Rad-RN obtains a brief history from the ICU nurse and performs a visual assessment of Miss Murphy. Vital signs are noted to be stable (Heart rate = 84 bpm, Respiratory rate = 12, Blood pressure = 160/90 mm Hg, SaO2 = 94%).

Performing the Procedure

Before lowering the HOB, the Rad-RN notes mild intracranial hypertension (ICP = 17 mm Hg). The ICU-RN and Rad-RN agree to drain 3 mL of CSF drainage and ensure that the ICP has normalized before transferring Miss Murphy onto the CT table. During the transfer, the ICU-RN positions herself near the HOB to monitor the EVD and the Rad-RN monitors the IV catheters. While the ICU-RN hangs the EDMS and performs a quick neurological assessment, the Rad-RN confirms IV patency and secures the power injector tubing for contrast. Imaging is quickly accomplished and nurses, transport tech, and respiratory therapist help to transfer Miss Murphy back to bed.

Transport Back to the Patient's Room

The respiratory therapist notes that the patient's oxygen cannula had been displaced and repositions it to administer supplemental oxygen via nasal cannula at 2 L/min. The team then transports the patient back to the ICU without incident where the ICU nurse reconnects all of the telemetry monitoring, levels the EVD to the patient's tragus, and verifies that the monitor displays a normal ICP waveform (Figure 2).

Completion of a Safety and Monitoring Assessment After Transport

The ICU nurse performs a postprocedural comprehensive assessment and completes required documentation.

Correct Actions

This is a classic case in which everything goes as planned. There was strong communication, and the patient was stable throughout. By not immediately lowering the HOB, the radiology nurse avoided a prolonged episode of intracranial hypertension (treated by CSF drainage). Shared responsibility allowed the ICU-RN to focus her attention on ensuring that the EVD and EDMS were secure, the Rad-RN to focus on contrast administration, the respiratory therapist to manage oxygenation, and the CT technologist to focus on obtaining the required images.

Teaching Tips

Reflecting on this case provides clues to successful transportation and ensures the safety of the patient. Despite both nurses remaining in the control room throughout the procedure, the use of handoff or handover communication techniques is advised for all intrahospital transports (Colvin et al., 2016; Dixon et al., 2015).

The Monro-Kellie doctrine is often discussed to describe the intracranial vault. The doctrine states that there are 3 primary components inside the skull: 10% is blood, 10% is CSF, and 80% is brain/tissue (Malloy and March, 2016). One function of the EVD is to facilitate CSF drainage under the assumption that a reduction in one of the three components (in this case CSF) will result in an overall reduction of the intracranial volume and thereby a reduction in ICP. Had the team lowered the HOB for the CT scan without first draining CSF, there could have been a sudden increase in the volume of blood entering the skull, resulting in a further increase in ICP.

The ICU nurse kept the EDMS hanging with the transducer leveled at the foramen of Monro (tragus of the ear). It is vital to note the positioning of the EDMS, especially the burette (drip chamber). The top of the burette has a filter to allow air to enter and exit, thereby avoiding a vacuum effect. Never rest the EDMS on the patient during transportation or imaging; if the filter becomes wet, it may prevent the passage of air and result in malfunction or inaccurate ICP readings. A few EVD companies are beginning to manufacture EDMS with oleophobic filters. This may result in a practice change, but current best practice is to always secure the EDMS in a vertical position (e.g., on an IV pole).

Transport for emergency angiogram

In the afternoon of day 7, Miss Murphy is found to have a significant change in her neurological status. Her NIHSS has increased to 12, and the results from a transcranial Doppler (TCD) study performed earlier in the day suggest that she is experiencing cerebral arterial vasospasm. New onset of aphasia and right arm weakness combined with TCD left middle cerebral artery (MCA) mean velocities of 250 cm/sec (Lindegaard ratio = 3.6) further support that this is most likely due to vasospasm of the left MCA (Mastantuono et al., 2018). Noting that she could likely benefit from angioplasty, the neurosurgery team orders a stat angiogram with possible angioplasty.

As the ICU-RN caring for Miss Murphy leaves the room to inform the family, she asks a colleague to prepare Miss Murphy for transport. The neurosurgery team had notified the interventional radiology (IR) team, and they are prepping the room for the procedure when the patient arrives unannounced. Upon arrival to the IR suite, the EVD was clamped (not draining CSF), and the EDMS was laying on the patient's chest.

After assisting with a quick transfer from bed to the procedure table, the Rad-RN hangs the EDMS from a nearby IV pole, confirms that the transducer is level with the tragus, and notes the following vital signs: Heart rate = 112 bpm, Blood pressure = 186/88 mm Hg, and ICP = 24 mm Hg with a severely dampened waveform. The ICU-RN opens the stopcock to allow CSF to drain and then leaves the IR suite stating she is going to obtain a dose of hypertonic saline (23.4% NaCl). She does not communicate with the Rad-RN about the amount of CSF she expects to drain. Before her return, the interventionist arrives and quickly raises the table to accommodate his working height.

The ICU-RN returns a few minutes later and notes that over 18 ml of CSF has drained from the EVD through the EDMS and into the collection chamber. The EVD is immediately clamped and the transducer releveled. The ICP values initially read −2 mmHg. After a zero-calibration is performed, the ICP is 6 mmHg with a poor waveform. Knowing that ICP values fluctuate, the Rad-RN advises to wait before further action is taken. Within 10 minutes, the ICP raised to >20 mm Hg (Rogers et al., 2017). The ICU-RN programs the IV pump to deliver 30 mL of 23.4% NaCl over 15 minutes through a central venous catheter. She then leaves the procedure room.

Approximately 7 minutes later, the ICP is noted to be 26 mmHg. A quick assessment confirms that the central venous catheter had become occluded. After restoring patency, the infusion is resumed, and the patient receives the rest of the 23.4% NaCl bolus. The ICP steadily decreases over the next 15 minutes to 12 mmHg.

Over the next 4 hours, the interventional neuroradiologist will be able to restore complete patency to Miss Murphy's left MCA. She is transferred back to the ICU, and the Rad-RN gives report with a complete handoff to the ICU-RN. Upon arrival from the angiography suite, the nurse settles the patient and reconnects the EVD transducer to the monitor. The EDMS is repositioned in level to the patient's tragus, but even after replacement, the ICU-RN notices that the ICP waveform appears severely dampened. This leads the ICU-RN to suspect that the EVD catheter may have been displaced or occluded. The neurosurgery resident is informed, and the EVD catheter patency is reestablished by flushing with preservative-free saline.

Correct Actions

The case is purposely crafted to demonstrate the potentially profound effect of seemingly minor actions. After recognizing that

Figure 2. Normal ICP waveform with stairstep descending waves (P1, P2, P3). ICP = intracranial pressure; ART = Arterial Line; ECG = Electrocardiogram.

the change in table height resulted in the sudden excessive amount of CSF drainage, the EVD was immediately clamped. This is a correct action; it would have been risky to just raise it back up because they could have entrained air into the ventricles. Furthermore, overdrainge of ICP can lead to intracranial hypotension and the development of subdural hematomas from a rupture of the intracranial bridging veins. Continuous monitoring of the ICP led the RN to evaluate and then restore the patency of the IV. Finally, the team did perform a throughout handoff at the end of the procedure.

Teaching Point

Closed-loop communication is imperative in this setting. The ICU team did not coordinate the transfer with radiology, and the patient arrived unannounced. When the nurse placed the EVD on the patient's chest instead of an IV pole, the integrity of the filter may have been impaired. Thus, when the ICU-RN zeroed the transducer, a poor (dampened) waveform was noted. This could indicate inaccurate ICP readings. The EVD would most likely need to be changed, requiring an extra procedure for the patient.

There was no clear handoff before the start of the procedure, and the RNs did not communicate with each other regarding EVD management. When the ICU-RN did not inform the Rad-RN the amount of CSF she was hoping to drain in an effort to decrease the ICP, this left the patient's EVD unattended while the CSF was draining. Therefore, when the interventionist raised the table, there was a relative (but not actual) change in pressure when the patient's head was significantly higher than the EDMS reference point (stopcock). The ICU-RN was not present and therefore unable to warn the interventionist about the open EVD; the Rad-RN was not given this information, and this resulted in a large amount of CSF drainage. Finally, the EVD catheter itself was probably malfunctioning during the latter half of the procedure, and this was unrecognized.

Discussion

Communication plays a major role when transporting a patient. In each of the aforementioned intrahospital transport scenarios, effective communication was vital. However, understanding how the EVD and EDMS provide an accurate ICP value is equally important. Closed-loop communication is used to ensure that all parties are aware and understand what is needed for the patient at that moment. When giving handoff, it is valuable to mention the patient's diagnosis and reasoning for the EVD. Also it is beneficial for the primary nurse to provide the ordered ICP level so that if the radiologic technologist or RN notices a spike in the pressure that sustains, that person will be able to bring it to the primary RN's attention. At this time, proper steps will be taken to decrease the ICP.

Closed-loop communication and the use of handoff communication tools are linked to reduced intrahospital transport-associated errors. The entire team should be updated on any patient care intervention so that everyone is aware and can minimize disruptions that could potentially pose harm to the patient. Patients with neurological injury, especially those who require ICP monitoring, are at high risk for secondary brain injury (Ortega-Perez and Amaya-Rey, 2018). Care of the patient with ICP monitoring during radiographic imaging requires that the system being used be accurately referenced to the patient and conditions.

Planning and communication are top factors to reducing intrahospital transport complications to and from radiology (Ott et al., 2011). Given an increased risk to patients, there is an increased need for vigilance in monitoring during transport (Ott et al., 2015). The Rad-RN has training in both the discipline of nursing and in radiographic imaging and is therefore in a unique position to significantly impact patient outcomes (Werthman, 2018). However, if the Rad-RN is not adequately informed of the patient's status, this opportunity is drastically reduced. Therefore, the ICU-RN and Rad-RN need to communicate. Standardizing communication has been shown to improve patient outcomes (Tam et al., 2018).

Communication should be as specific to the patient as possible. The use of the NIHSS score is growing as a validated assessment of ischemic stroke, and this was used to help convey information for Miss Murphy. The NIHSS is an 11-item scoring tool in which a score of 0 is assigned to patients with no stroke deficits and higher scores indicate worsening. Although she was admitted with a hemorrhagic stroke, many hospitals have adopted the use of serial assessment of NIHSS after SAH to observe for cerebral artery vasospasm, which commonly occurs after an SAH. In the first scenario, the NIHSS of 1 indicates a minor stroke. In the second scenario, the NIHSS of 12 indicates a moderate to severe stroke.

Measurement of ICP remains a vital assessment when caring for a neurologically ill patient. Positioning of the patient can either increase or decrease ICP. Therefore, registered nurses and radiologic technologists must take into account the position of the patient during transport and imaging. Critically ill patients who stay in a supine position for long periods tend to show increased ICP. By elevating the HOB, adequate cerebral perfusion may be achieved (Altun Ugras et al., 2018). When positioning a patient with an EVD, first clamp the patient by turning the system stopcock off toward the patient. This will stop the flow of CSF into the collection chamber. Failing to clamp the system could lead to over drainage of CSF, with attending complications. Pathological events that increase the ICP above 20 mmHg for more than 5 minutes are potentially life-threatening and could lead to supratentorial or infratentorial herniation and/or decreased cerebral blood flow (Malloy and March, 2016).

Conclusion

Critically ill neurological and neurosurgical patients, especially those who require ICP monitoring, often return to radiology setting frequently for follow-up imaging and for procedures. These patients are at a higher than normal risk for secondary brain injury during transport. As seen in the case exemplars, safe repositioning of patients with EVD requires knowledge of CSF and ICP dynamics and a good understanding of the ICP-monitoring system. There are currently no clear guidelines for this interdepartmental transportation of the neurocompromised patient with an EVD. Knowledge of device functionality combined with safe transport will begin to establish best practice for transportation and monitoring of a neurologically compromised patient to radiology. Clear and accurate communication between neurology, neurosurgery, and radiology nursing teams is expected to reduce transport- and imaging-associated patient complications.

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