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Take Notice Technology

Erroneous Intracranial Pressure Measurements From Simultaneous Pressure Monitoring and Ventricular Drainage Catheters

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Abstract

The objective of this report is to highlight the potential for false pressure measurements from systems that combine intracranial pressure (ICP) measurement and ventricular drainage. If the ports of the drain become blocked to the extent that they present a high resistance to cerebrospinal fluid flow, then a significant pressure gradient between the inside and outside of the catheter may be established. Thus, any intracatheter transducer will faithfully record a pressure much lower than true ICP. This holds true for catheter-tip transducers when the transducer lies inside the catheter. In the absence of flow, however, pressures will equalize; therefore, accurate measurements may be taken if the drain is temporarily closed. We model this situation and provide simulations of expected measurements in such situations; these compare well to observed clinical readings.

Key Words: Intracranial pressure; cerebrospinal fluid; ventricular drainage.

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Background

Simultaneous intracranial pressure (ICP) measurement and ventricular drainage has been shown to be misleading when pressure is measured via a fluid-filled coupling to the extracranial ventricular drain *(1)*. This is because cerebrospinal fluid (CSF) flow in the drain generates a pressure gradient in the draining catheter. Only by sampling from within the ventricle can the true ICP be measured. The emergence of catheter tip pressure transducers in the 1990s effectively removed this source of error and enabled reliable measurements *(2)*. Whereas for older systems the pressure transducer was mounted on the outside of the ventricular drain, some of the current commercially available combined systems have the transducers inside the tip of the catheter. Although under most conditions, a reliable measurement of ICP is made, we wish to highlight circumstances under which false readings may occur.

Case Report

A 38-year-old man was admitted to our unit having suffered severe head injuries following a road traffic accident. A combined ventricular drain/pressure monitoring device (Camino Micro Ventricular Bolt Pressure Monitoring Kit Model 110-4HM, INTEGRA™ Neurosciences, San Diego, CA) was inserted into the left lateral ventricle. The height of the ventricular drainage system was set to maintain an ICP of approximately 15 mmHg. The drain had been in place for 24 hours and was draining steadily at a rate of 10–20 mL/hour. ICP was continuously monitored and found to be at 15 mmHg, as expected. On the morning of the second day, the ICP measured with the drain tap open remained at 15 mmHg, but when the drain was closed, the ICP measurement rose instantaneously to a new stable but more pulsatile level of 30 mmHg. When the drain was reopened the pressure measurement immediately returned to 15 mmHg. These step-like changes in pressure were shown to be repeatable. The timescale of changes was far shorter than that which could be attributed to the slow build up of CSF in the ventricles owing to the absence of drainage (>0.006 mL/second).

Model

We hypothesise that the discrepancy was a result of blocked catheter ports, and that the true ICP was recorded only when the catheter was closed. The situation is modelled in Figure 1.

Theoretical Simulation

The model setup shown in Figure 1 was simulated using simple fluid dynamics; for a detailed description of such mathematical models see for example the analogous system of Schley et al. *(3)*. The system input was a pulsatile ICP with mean 30 mmHg. Ventricular build-up of CSF in the absence of drainage was assumed to be significantly higher than the 10–20 mL/hour recorded in the previous case report in order to be visible over the timescale of the simulation; this also clearly indicates that this factor alone is not sufficient to explain the observed changes. Results are shown in Figure 2 and compare favorably with clinical observations.

Experimental Simulation

An identical catheter to that used in the case study was used in a physical model to determine the degree of catheter obstruction required to produce a significant pressure gradient. An infusion pump was used to drive 0.9% saline solution through the catheter, simulating CSF drainage. Two cross-calibrated pressure transducers (Camino Micro Ventricular Bolt Pressure Monitoring Kit Model 110-4HM, INTEGRA™ Neurosciences) were used to monitor pressure, one placed inside and one immediately outside the catheter. Different degrees of catheter obstruction were achieved by blocking the catheters drainage holes with small plastic plugs. Complete or partial blockage of each of the 20 holes could be achieved by selecting a full circle or half circle plug. The results are summarized in Table 1.

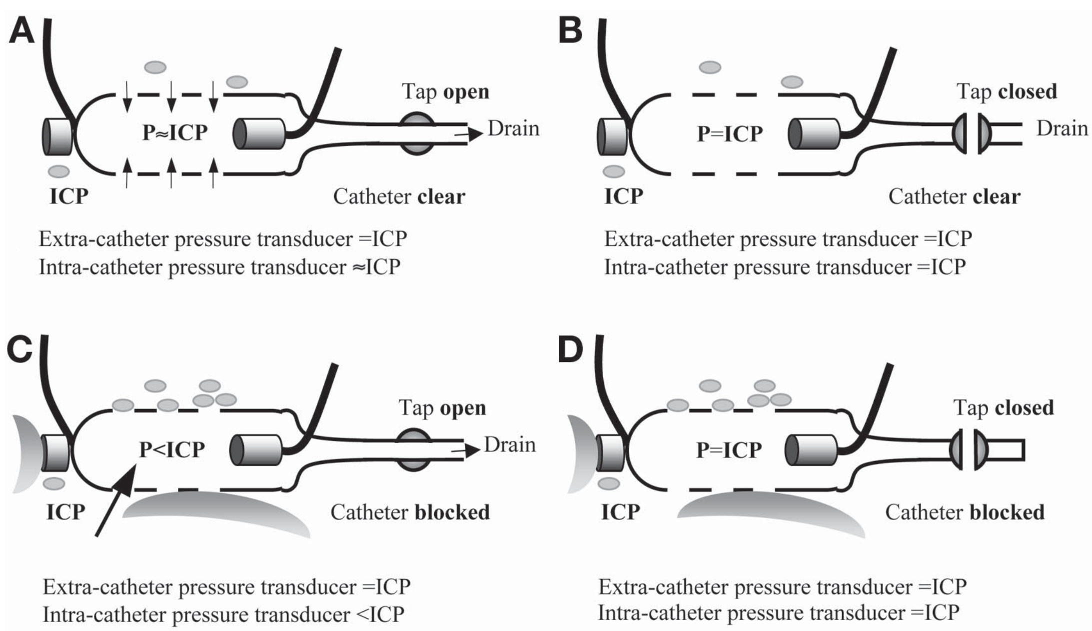

Fig. 1. A functioning catheter **(A)** offers little resistance to flow, so that very little difference between the ICP outside and the pressure inside is required to push CSF into the catheter. When the drain is closed **(B)**, no flow occurs and the pressure is uniform throughout the system above the tap. If holes in the catheter become blocked **(C)** by the ventricle walls or intraventricular debris (including bloody and/or highly proteinic CSF), the resistance of the catheter becomes significant. A large pressure difference may be required to force flow through, so that intracatheter pressure measurements fail to be a true indicator of extracatheter ICP. If the system is temporarily closed, however, **(D)** the pressures again quickly equalize so that ICP readings can be taken.

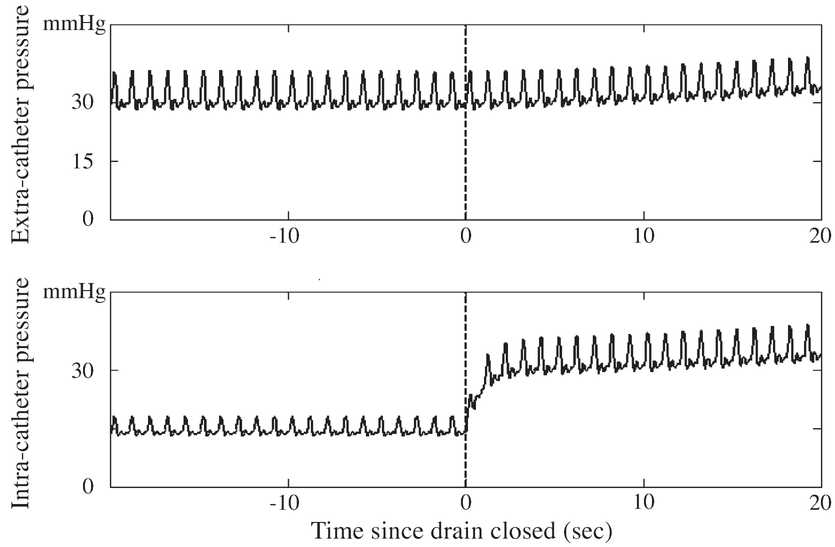

Fig. 2. Simulations of the model for a blocked catheter predict behavior in agreement with that observed in the previous case report. Extracatheter pressure (top), reflecting true ICP, increases gradually when the drain is closed because of the build-up of excess fluid in the ventricles, but this occurs relatively slowly over a matter of minutes. Intracatheter pressure (bottom) will be much lower if there is severe blockage resulting in a significant pressure gradient across the ports, which also dampens the magnitude of oscillations. The pressure gradient is removed in the absence of flow, so that when the drain is closed intracatheter pressure quickly rises to that elsewhere in the system. This change is near instantaneous and on a different time scale to the subsequent slow additional rise in pressure to the accumulation of fluid.

Discussion

Bench-top experiments show that the resistance to flow through the Camino Micro Ventricular Bolt Pressure Monitoring kit is extremely low, and it is not until near complete blockage of all drainage holes that the resistance may be sufficient to generate a significant pressure gradient. However, this scenario is not necessarily as rare as one might expect and may be a common occurrence when the ventricle walls close around the catheter. Under these conditions, a flow channel with compliant walls may remain between the inside of the catheter and a fluid-filled part of the ventricle. This channel would behave as a Starling resistor, with a very high-resistance pinch-point forming where flow exits the channel. An increase in ICP squeezes the channel, increasing the resistance to flow and increasing the pressure gradient generated. A similar mechanism is known to operate at the cerebral venous outflow when ICP exceeds jugular pressure *(4,5)*.

Table 1
Pressure Gradient Between Inside and Outside of the Catheter With Different Degrees of Blockage at Different Flow Rates

Flow (mL/hour)	*Holes completely blocked*	*Holes partially blocked*	*Pressure gradient (mmHg)*
15	0/20	0/20	< 1
15	19/20	0/20	< 1
190	19/20	1/20	3

Significant flow through a high-resistance channel requires a large pressure gradient between the ICP and the inside of the drain. The pressure drop is a feature of the flow of CSF into the drain, and when that flow is stopped (the drainage tap is closed) then the pressures equilibrate at close to the true ICP pressure because the catheter has relatively low compliance compared to the ventricles.

Closure of the drain would be expected to lead to a gradual increase in ICP as CSF volume increased. An immediate increase in ICP, such as that observed, cannot occur as a result of increased CSF volume. The only reasonable explanation for this unexpected discrepancy is provided by a consideration of fluid dynamics.

This means that for intracatheter pressure transducers, the true ICP pressure is the closed reading and not the open one. The pressure transducer is faithfully recording the pressure of its environment, but when the holes are almost completely blocked and the CSF flow is high then the pressure within the catheter is not the same as the pressure in the ventricle. It is not envisaged that such an error will occur with combined systems where the pressure transducer is mounted outside of the catheter, because fluid pressure will simply be transmitted via any matter pressing onto the transducer *(1)*; such systems are expected to produce near identical (true) readings whether open or closed.

It is unfortunate that no data was recorded for the case report, because the significance of the situation only came to the attention of the authors later. We can confirm, however, that there is good qualitative agreement between simulations and the clinical observations, and believe that the output described will already be familiar to many neurointensivists.

Conclusion

Intracatheter tip ICP monitoring inside a ventricular drain is susceptible to error when the catheter is partially blocked; this error is thought unlikely to occur with extracatheter mounted transducers. When a discrepancy is observed between measurements made with the drainage tap open and those with it closed, the closed measurement should be used as the true reading of ICP. Practice at the bedside should include closing the system at least hourly to obtain a true (closed) reading of the ICP.

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