

The Camino Intracranial Pressure Sensor: Is it Optimal Technology? An Internal Audit with a Review of Current Intracranial Pressure Monitoring Technologies

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OBJECTIVE: To audit the reliability of the Camino intracranial pressure (ICP) sensor (Camino Laboratories, San Diego, CA) in our clinical practice as part of a continuing quality assurance program, and to assess its relative usefulness as compared with currently available ICP monitoring technologies that we reviewed.

DESIGN: Prospective audit of ICP device reliability and function in 50 patients with head injuries.

METHODS: Zero drift was recorded immediately after the ICP device was removed from the patient. Dynamic frequency response bench testing of each functioning catheter from 0 to 30 Hz and static calibration testing from 0 to 100 mm Hg during environmental temperature variation from 22 to 40°C were carried out.

RESULTS: Zero drift (range, -13 to 22 mm Hg; median, -1 mm Hg) was recorded immediately after the devices were removed from patients. Seventeen (50%) of the devices tested for zero drift had absolute drifts of at least 3 mm Hg. There was no correlation between recorded zero drift and duration of monitoring ($r = 0.154$, $P = 0.207$). Five sensors (10% of those tested) failed during patient monitoring and were replaced. Static and dynamic calibration tests of the functioning sensors were within the manufacturer's specifications. However, the sensitivity of the devices to environmental temperature remains a problem.

CONCLUSION: The Camino ICP sensor remains one of the most popular ICP monitoring devices for use in patients with traumatic brain injuries. However, our recent in-house assessment demonstrated the robustness of the device to be less than adequate during routine practice. In this study, more than 50% exhibited zero drift greater than 3 mm Hg, which is unacceptable in a catheter tip ICP monitoring device in which zero drift and calibration cannot be checked in vivo. A review of the literature revealed that other available ICP monitoring devices may prove to be more reliable and thus more appropriate for routine clinical measurement of ICP.

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Key words: Health care technology assessment, Intracranial pressure measurement

The Camino fiberoptic intracranial pressure (ICP) monitor (Camino Laboratories, San Diego, CA) is one of the standard instruments currently in use for measurement of ICP in patients with traumatic brain injury. Since Ostrup first described it in 1987 (17), the system has been used widely in Europe and the United States.

In common with most other catheter tip transducer systems, a pressure calibration cannot be performed in vivo in the Camino system. After the Camino system is zeroed relative to atmospheric pressure during a preinsertion calibration, its pressure output is dependent on zero drift of the sensor. An electrical calibration is provided so that external monitors

can be recalibrated, but it cannot correct for inherent zero drift of the catheter once the catheter is placed.

The manufacturer's specification of the zero drift of the catheter is ± 2 mm Hg for the first day and then ± 1 mm Hg/d thereafter. Bench test studies have confirmed these findings (6). In clinical practice, however, the zero drift observed upon removal of the device from the patient has recently been reported to be greater than the manufacturer's specifications. Munch et al. (16) assessed 136 Camino sensors in a clinical study and reported an average daily drift rate of 3.2 mm Hg. With the increasing acknowledgment of the importance of maintaining optimal cerebral perfusion pressure (CPP) in the

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management of patients with severe head injuries (4), the use of stable, robust ICP monitoring technology is critical. There are also reports describing Camino probe failure because of technical complications (e.g., cable kinking, probe dislocation), with failure rates ranging from 10 to 25% (5, 21, 23).

These studies, in combination with in-house reports of Camino failure, prompted a prospective reassessment of the robustness and drift characteristics of the Camino sensor in our unit. This report presents the results of our in-house audit of the Camino 110-4B ICP monitoring kit and reviews the literature describing other currently available methods for the measurement of ICP.

MATERIALS AND METHODS

Fifty Camino 110-4B ICP sensors were assessed prospectively during an 11-month period. Although this sample size is small in comparison with some reported studies, it represents the typical annual placement rate of ICP monitoring devices in patients with severe head injuries in our unit. A larger sample would not have been feasible as part of an annual internal audit.

The sensor was placed according to the manufacturer's instructions. Before placement of the probe, the sensor was held at the level of the external auditory canal. If the monitor did not display a stable zero value, then the "zero screw" was adjusted appropriately. The catheter was then inserted to a depth of 5 cm from the top of the fixation bolt, which placed the tip of the catheter into the subarachnoid space.

The Camino monitor (420 or MPM-1) was connected to a bedside patient monitor (Agilent Technologies, Boblingen, Germany) via a standard interface cable. All ICP data were recorded as 1-minute averages and stored in an intensive care unit data server. Nurses were given an ICP monitoring audit form that contained guidelines for recording the sensor reading after removal of the catheter from the patient. Recovered

sensors were sent to the Department of Medical Physics for bench test assessment.

Calibration

In accordance with standard nursing management practice in our intensive care unit, the Camino's electrical zero was checked and the bedside monitor was zeroed appropriately once per 12-hour nursing shift. After removal of the Camino sensor from the patient, the tip of the sensor was again held at the level of the external auditory canal and, after verification that the Camino readout was stable for 10 seconds, the value displayed on the Camino unit (not the bedside monitor) was recorded on the audit form.

Bench Tests

After Camino sensors were removed from patients, they were disinfected by being soaked for 60 minutes in a solution of 0.25 mol/L sodium dichloroisocyanurate. The sensors were handled with gloves at all times. They were fixed within a 10-ml fluid-filled syringe by creating a hole in a rubber bung and sealing the apparatus with epoxy-resin glue. The ISO-9001 Calibrated MEDEX MX2000 static pressure calibrator (Medex, Inc., Hilliard, OH) was attached to the other end of the syringe with a 100-cm length of low compliance extension tubing and a three-way tap. The syringe was submerged in a heated water bath to the same height as the external pressure generator. The temperature in the water bath was measured with a digital thermometer. Pressure measurements were then taken by moving first up the scale and then down the scale between 0 to 100 mm Hg in increments of 5 mm Hg. Measurements were repeated at water bath temperatures of 22, 25, 29, 33, 37, and 40°C.

Analyses

Summary statistics for zero drift were calculated (range, mean, median, maximum difference, and percentage of time

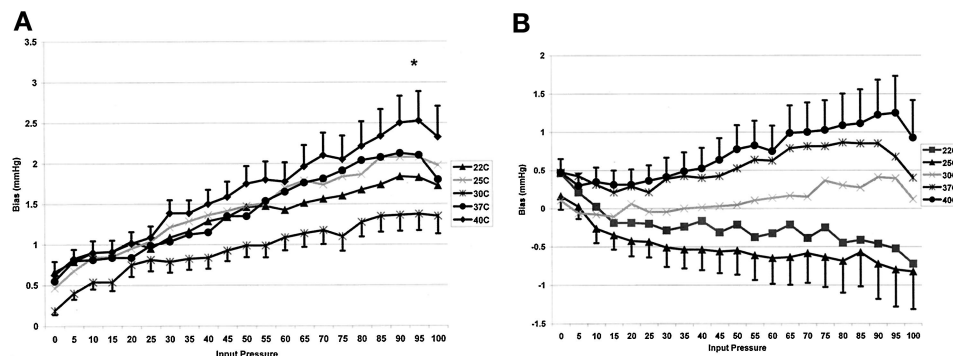


FIGURE 1. Line graph summarizing the results of the input calibration pressure and water bath temperature calibration bench tests. *A*, absolute difference (bias: independent of sign) between the Camino recorded pressure and the input calibration pressure over a range of pressures (0–100 mm Hg) and water bath temperatures (22–40°C). Repeated measures analysis of variance has shown that

the observed bias is pressure-dependent ($*P = 0.002$) with a significant interaction between pressure dependence and water bath temperature ($P = 0.018$). *B*, actual bias (sign-dependent). As temperature increases, the bias increases in a positive direction.

spent ≥ 3 mm Hg) and expressed in terms of absolute drift as well as of drift normalized per day of monitoring. Data regarding the static calibration and temperature sensitivity are shown graphically (Fig. 1). To test for an effect of pressure or temperature on the observed bias in pressure measured during the static calibration tests, a linear repeated measures analysis of variance model was fitted. Dynamic frequency response test results are shown in the form of a frequency response plot with the output amplitude of the Camino sensor expressed as a percentage of the input amplitude (in mm Hg) plotted against test frequency (Fig. 2).

RESULTS

During the period of the audit, 50 Camino catheters were placed in patients. Five catheters failed during patient monitoring. The catheters that failed either showed abrupt, abnormally high readings (>200 mm Hg) or gave no reading at all, with the display showing a series of dashes. There was no relationship between the duration of monitoring and failure. Five catheters that functioned normally in the patient could not be tested after removal from the patient because of high-risk contamination of the probe ($n = 1$), bent fiberoptic tip ($n = 1$), broken connector ($n = 1$), and adhesive tape wound around the tip of the sensor that could not be removed without damaging the catheter ($n = 2$). The damage to the catheters with the bent tip and the broken connector must have occurred between the time when the sensor was removed from the patient and its arrival at the testing laboratory. The other 40 functioning catheters were available for bench testing (Table 1). In addition, with regard to six catheters in which zero drift was displayed immediately after removal of the catheter from the patient, either the nurses did not record the data ($n = 4$) or an incorrect zero-drift recording procedure was followed ($n = 2$). For the reasons described above, of the 50 catheters prospectively included in the audit, 40 catheters were functioning immediately after removal and thus were

available for bench tests. Correct zero-drift values were recorded in 34 of those 40 catheters (Table 1).

Table 2 summarizes the zero-drift data and its distribution in the sensors available for bench testing and assessment of zero drift. The mean time of monitoring was 4 days but ranged from 1 to 12 days overall (median, 3 d). Zero drift recorded immediately after removal of the catheter from the patient ranged from -13 mm Hg to 22 mm Hg. Mean and median drift for all catheters were within the manufacturer's specifications (mean, -0.67 ; median, -1 mm Hg). More than 50% of the catheters, however, exhibited a total zero drift greater than ± 3 mm Hg after being removed from the patient. After the total zero drift was normalized to the number of days of monitoring (zero drift divided by days of monitoring), only 6% of the catheters exhibited a zero drift greater than 3 mm Hg. No significant correlation was found between zero drift and duration of monitoring ($r = 0.146$, $P = 0.617$).

Figure 1 summarizes the bench test results obtained after assessment of the pressure and temperature calibration. Figure 1A is a graph showing the absolute difference (bias: independent of sign) between the Camino-recorded pressure and the input calibration pressure for a range of pressures (0–100 mm Hg) and water bath temperatures (22–40°C). Repeated measures analysis of variance has shown that the observed bias is pressure-dependent ($P = 0.002$), with a significant interaction between pressure dependence and water bath temperature ($P = 0.018$). Figure 1B is a graph of the actual bias (sign-dependent). As temperature increases, the bias increases in a positive direction. For example, at a test pressure of 40 mm Hg, the bias at 25°C is -0.5 mm Hg, which increases to a positive bias of 0.5 mm Hg at 40°C, for a difference of 1 mm Hg.

Figure 2 shows the frequency response data for all catheters tested. The graph expresses the output pressure amplitude of the Camino system as a percentage of the input pressure signal amplitude across a range of frequencies from direct current through 30 Hz. As expected for a catheter tip transducer, the Camino system shows excellent frequency characteristics, with a

TABLE 1. Summary of Catheter Tests

Stage	No. of Catheters	Comments	Available for Bench Tests (Calibration, Temperature Sensitivity, Frequency Response)	Zero-Drift Value Properly Recorded
Study design	50			
Sensors placed	50			
Failed in situ	5			
Recovered from patient but unable to bench test	5	High risk of contamination ($n = 1$), broken connector ($n = 1$), bent tip ($n = 1$), adhesive tape covering sensor ($n = 2$)	40	
Nurses failed to record zero-drift value	4			
Incorrect zero-drift measurement procedure	2			34

TABLE 2. Monitoring Time and Zero-Drift Data^a

Data Measurement	Monitoring Time (in d)	Zero Drift (Absolute) (in mm Hg)	Zero Drift (per Day) (in mm Hg)
Maximum	12	22	2
Minimum	1	-13	-13
Mean	4.4	-0.67	-1.45
Median	3	-1	-0.38
Standard deviation	3.5	5.9	3.6
Percentage ≥ 3 -mm Hg Drift	—	50%	6%

^a n = 34 catheters. —, no data.

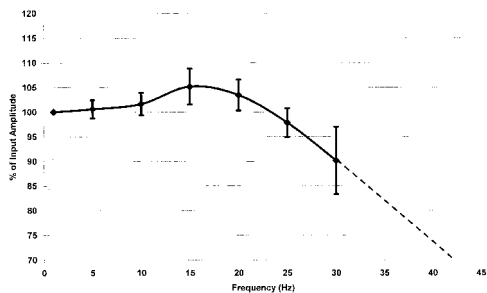


FIGURE 2. Line graph showing the frequency response data for all catheters tested. The graph expresses the output pressure ampli-

tude of the Camino system as a percentage of the input pressure signal amplitude over a range of frequencies from DC up to and including 30 Hz. As expected for a catheter tip transducer, the Camino system shows excellent frequency characteristics with a flat frequency response to 25 Hz and an estimated "half-power" point (-3 dB down) at 43 Hz.

flat frequency response to 25 Hz and a "half-power" point (-3 dB down) at 43 Hz. The rolloff results from the Camino monitor's output filtering rather than from the frequency response of the catheter tip sensor. The frequency response is more than adequate for the purposes of ICP waveform analysis.

DISCUSSION

This study, prompted by our routine biomedical equipment quality assurance program, provides data regarding robustness and zero drift recorded during our department's use of the Camino fiberoptic ICP monitor. Surprisingly, even after nearly a decade of experience in using this device in our department, the rate of zero drift and device failure is unexpectedly high. The duration of the study, 11 months, together with no obvious placement bias by any particular surgeon, minimizes the effect of operator bias on the results. Also, if there were an operator bias present, it would be more likely that those devices that failed or showed a large drift would have done so sooner after placement than did other sensors. This circumstance did not occur, because no correlation could be found between the degree of zero drift and the duration of monitoring ($r = 0.146$, $P = 0.617$). Although drift is expressed as both absolute drift (total amount divided by whole duration) and the amount of drift per day (total drift divided by days of monitoring), the former value is more pertinent. Be-

cause no correlation was found between the degree of zero drift and the duration of monitoring, whether the total zero drift occurred on the first or the last day or developed gradually for the duration of monitoring is not known. With catheter tip technology that cannot be zeroed in vivo, there is simply no means of ascertaining the rate of zero drift. In the assessment of devices used to guide therapy for raised ICP, we must assume the worst-case scenario.

A 10% failure rate and 50% of catheters with a total drift of more than 3 mm Hg is unacceptable, particularly because increasing emphasis is being placed on CPP threshold therapy in the management of patients with head injuries, in whom accurate measures of CPP and hence also ICP are required. Our dissatisfaction with the in-house audit of our current ICP monitoring technology has prompted our group to review current options for ICP monitoring.

Fluid-filled Catheter Transducer Systems

The standard intraventricular catheter connected to an external strain gauge transducer is termed a *catheter-transducer system* because it behaves, in many ways, like a mechanical system with a *mass* of fluid that acts against the springlike elastic properties of the catheter walls and the transducer diaphragm. This type of system first found widespread use in the 1960s and 1970s after Lundberg's (12) pioneering work on long-term ICP monitoring. Most publications in this field still refer to intraventricular monitoring as the "gold standard" method of measuring ICP, for three reasons. First, this method allows the clinician to check for zero drift and the sensitivity of the measurement system in vivo. Second, pressure measurement within the cerebrospinal fluid (CSF) space transduces pressure within a medium that is an incompressible fluid and, provided that CSF flow is not blocked, is not subject to the development of intracompartmental pressure gradients. Third, access to the CSF space provides a method of ICP treatment via CSF drainage. Concerns are often expressed, however, with regard to the increased risks of infection associated with ventriculostomy. Although a range of infection rates have been reported, with some being as high as 40% (20), recent reports confirm that infection rates are approximately 1%, which is not considered a prohibitive risk (3, 13).

The Head Injury Management Guidelines published by the Brain Trauma Foundation in 2000 recommend intraventricu-

lar ICP measurement as the first-line approach to monitoring ICP:

In the current state of technology, the ventricular catheter connected to an external strain gauge is the most accurate, low-cost, and reliable method of monitoring intracranial pressure (ICP). It also allows therapeutic cerebrospinal fluid drainage. (3, p 497)

Despite the existence of these guidelines (3, 13), catheter tip intraparenchymal pressure monitoring remains popular, particularly in the United Kingdom, because it does not require catheter placement in the operating theater and thus requires significantly fewer resources.

However, the routine use of fluid-filled catheter-transducer systems is not without difficulties. A catheter-transducer system can be described as a second-order mechanical system that, if underdamped, oscillates at its own natural frequency, producing significant amplitude and phase distortion of the pressure signal. The degree of distortion depends on the damping factor (β) of the system. For most purposes, a β of 0.64 is optimal because the amplitude error will be less than 2% for as much as two-thirds of the natural frequency of the system (9). Typically, most pressure catheter-transducer systems used in patients tend to be underdamped, with $\beta < 0.4$ (9, 18). Manipulating a catheter-transducer system from underdamped ($\beta < 0.3$) to overdamped ($\beta > 0.8$) can cause a 7-mm Hg decrease in mean pressure. Commercial devices that can alter the damping characteristics of external strain gauge pressure transducers and bring them within the range of optimal damping are available. An example of such a device is the Accudynamic adjustable damping device (Abbott Laboratories, Abbott Park, IL) (1).

Another problem with fluid-filled catheter-transducer systems is the necessity of correcting for the presence of hydrostatic pressure gradients when measuring CPP. Typically, the external strain gauge transducer is zeroed at the same level as the arterial blood pressure transducer, usually at the level of the right atrium. While the patient is managed in the horizontal position, there is no column of fluid between the site of ICP and blood pressure measurement. If the patient is managed with the head tilted upward and if the blood pressure transducer is not moved to the same horizontal level as the head, a hydrostatic fluid column is created. This positioning can produce a significant discrepancy between the observed and actual CPP; in the worst case, the discrepancy can be as great as 15 mm Hg.

The Spiegelberg ICP monitoring system (Spiegelberg KG, Hamburg, Germany) largely overcomes these problems. This system is a special type of fluid-filled catheter-transducer system. In this system, ICP is measured with a catheter that has an air pouch balloon situated at the tip. The air pouch method is based on that of Marey and Chauveau (10). By maintaining a constant known volume of fluid within the air pouch, the pressure within the air pouch balloon is equivalent to the surrounding pressure or ICP. The internal air pouch balloon is transduced by an external strain gauge transducer, and because the fluid used for pressure transduction is air, the error in the pressure reading caused by an air column is

clinically insignificant. The design of this device also allows automatic in vivo zeroing of the ICP system and, in laboratory bench tests, showed the least zero drift in comparison with standard catheter tip ICP devices (7). This system is available in versions for use in epidural, subdural, intraparenchymal, and intraventricular sites. The intraventricular catheter is a double-lumen catheter that allows access to the CSF space for drainage. The Spiegelberg system, although it has many attractive features, is as yet a relatively little used system outside Germany, and its long-term clinical usefulness and robustness require evaluation.

Catheter Tip Transducer Systems

A number of catheter tip ICP monitoring systems are available, including Camino (17), Codman (Codman & Shurtleff, Inc., Raynham, MA) (14), Gaeltec (Gaeltec, Ltd., Dunvegan, Isle of Skye, Scotland) (15), and InnerSpace (InnerSpace Medical, Inc., Irvine, CA) (11) systems. The Gaeltec ICP/B solid-state miniature ICP transducers are designed for use in the epidural space and are reusable, and the zero reference can be checked in vivo. Reports of measurement artifacts (2) and decay in measurement quality associated with repeated use (15) have limited the widespread adoption of this technology, however.

The InnerSpace OPX 100 system (InnerSpace Medical) is, like the Camino system, a fiberoptic system. Bench test reports regarding this system show it to have good zero-drift and sensitivity stability (6). A recent clinical evaluation of this system in 51 patients, however, reported a high (17%) incidence of hematoma formation around the ICP sensor (11). The authors concluded that improved fixation of the catheter is required to minimize micromovements.

The two most frequently used catheter tip systems in the management of patients with head injuries are the Codman and Camino systems. Neither allows a pressure calibration to be performed in vivo. After these systems are zeroed relative to atmospheric pressure during a preinsertion calibration, their pressure output is dependent on zero drift of the sensor. For this reason, it is critical that these devices exhibit good long-term zero-drift characteristics. These devices provide an electrical calibration so that external monitors can be calibrated, but their recordings cannot be corrected for inherent zero drift of the catheter once the catheter is placed. The Camino device manufacturer's specification for zero drift of the catheter is ± 2 mm Hg for the first day and ± 1 mm Hg/d thereafter. Czosnyka et al. (6) confirmed these zero-drift findings in bench test studies, although they also reported, in agreement with our findings, that the temperature drift of the device was significant (0.3 mm Hg/1°C). They reported that if the transducer is zeroed before implantation at room temperature, the temperature-induced overreading can be as much as 5 mm Hg, depending on the patient's brain temperature. In clinical practice, the reported zero drift immediately after removal of the Camino device from the patient has been reported to be greater than the manufacturer's specifications. Munch et al. (16) assessed 136 Camino sensors in a clinical study and found an average *daily* drift rate of 3.2 mm Hg.

Chambers et al. (5), in a comparative study of the Camino ventricular catheter with an external fluid-filled catheter-transducer system, reported that only 60% of the readings were within 2 mm Hg of the gold standard method. There are also reports of Camino probe failure because of technical complications (e.g., cable kinking, probe dislocation) with reported failure rates ranging from 10 to 25% (5, 19, 21, 23).

The Codman transducer is a microminiature strain gauge within a titanium housing that is side-mounted at the tip of the catheter. Similarly to other transducers, bench test reports regarding this technology have been favorable (6, 18). Clinical evaluations, however, have revealed the presence of interpatient and inpatient biases that were independent of whether the device was compared with the Camino transducer or with an intraventricular catheter-transducer system (22). Fernandes et al. (8) found that in 24% of the recordings, the Codman sensor overread the Camino system by 5 mm Hg or more.

CONCLUSIONS

The Camino ICP sensor remains one of the most popular ICP monitors used in patients with traumatic brain injuries. The in-house assessment that we report here, however, demonstrates that the robustness of the device during routine clinical practice is questionable. In this study, more than 50% of the Camino catheters exhibited zero drift greater than 3 mm Hg, which is unacceptable in a catheter tip ICP monitoring device that cannot be recalibrated in vivo. A review of the literature indicates that other ICP monitoring devices are available that may prove to be more robust and thus more appropriate for routine clinical measurement of ICP.

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COMMENTS

Piper et al. describe a prospective study of 50 Camino intracranial pressure (ICP) sensors (Camino Laboratories, San Diego, CA) removed from patients with head injuries at the end of ICP monitoring (of unspecified duration). The authors' message is that the zero drift of the Camino sensor is unpredictable and too great for safe clinical use. It is not clear from the presentation that their conclusion is true. The authors should present a plot of the devices' drift versus days of monitoring for all 34 patients and indicate in how many cases the transducer's drift was outside the guaranteed region (2 mm Hg for the first day plus 1 mm Hg for each subsequent day).

Most neurosurgical groups that are experienced with ICP monitoring are happy if intraparenchymal ICP differs from ventricular fluid pressure by only 5 or 6 mm Hg. Moreover, with these probes, the site-to-site differences—particularly in the presence of substantial tissue swelling—are probably common; therefore, brain tissue pressure may differ substantially from cerebrospinal fluid pressure.

From the methodological point of view, it is unfortunate that zero drift measurements were performed in air rather than in a wet environment. Appropriate controls should have been included in the design of the study because the two environments may not lead to the same results. Any remaining tissue or protein residues drying on the microtransducer's tip might exert an artificial strain on the pressure-sensitive membrane and subsequently convert to the excessive pressure reading, thus leading to an erroneous recording of zero drift.

Defects and mechanical failure of microtransducers are not uncommon and often can be attributed to poor handling. One of the benefits of the Camino sensor system is that it tells the observer when something is wrong with a transducer.

The comparison of different ICP measurement systems in the Discussion is very helpful. We would add, however, that the air-filled Spiegelberg transducer has frequency properties that are far inferior to those of water-filled transducers and microtransducers (including the Camino sensor). Therefore, ICP waveform analysis, which is so important in various clinical and research scenarios, is impossible with the Spiegelberg device.

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Piper et al. prospectively studied the use of the very popular Camino ICP sensor on with head injuries. They examined a relatively small group of 50 patients. It was possible to evaluate 34 of 50 removed ICP sensors. The zero drift recordings ranged from –13 to 22 mm Hg. The Camino ICP sensor

was found to have a very high zero drift rate of more than 3 mm Hg in more than 50% of the patients studied. This high zero drift rate is unacceptably high, especially, as the authors underline, because the sensor cannot be checked in vivo. It also was necessary to replace 10% of the sensors because of device failure.

The authors review the different technologies of ICP monitoring in a very insightful way. Reviews such as this one are necessary and very important because of the great number of devices available for ICP monitoring, and these devices are nearly never evaluated before, during, and after use. In neurosurgical centers in which long-term ICP monitoring (for hours, days, or even weeks) is routine, the techniques and pitfalls of ICP monitoring are well known; but for centers in which neurosurgeons or neuroanesthesiologists want to begin using ICP measurements, access to critical reviews such as this one is of even more importance.

Direct ICP monitoring using an implanted catheter—whether in the ventricular system (gold standard) (1), in the brain substance itself, or in the epidural, subdural, or lumbar space—is a necessary and very valuable part of the neurosurgeon's daily armamentarium. New technologies (2) offer a variety of safe, practical sensors, both for the daily user and for newcomers to ICP monitoring.

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2. Vespa PM, Bergsneider M, Becker DP: Intracranial pressure monitoring: Operative procedure and technical considerations, in Kaye AH, Black PMcL (eds): *Operative Neurosurgery*. London, Churchill Livingstone, 1999, pp 1205–1213.

As has long been known in neurosurgery, all ICP-monitoring devices without the ability to accomplish in vivo zeroing are subject to measurement error because of drift. Clinicians have long been concerned with regard to the potential clinical significance of the drift of ICP readings in the positive or negative direction.

In this regard, Piper et al. provide their meticulous ex vivo bench dissection of the capabilities of Camino ICP sensors that were obtained from clinical monitoring situations. These authors raise alarm with regard to their findings that 50% of their sensors had greater than 3 mm Hg absolute drift and that 6% had greater than 3 mm Hg/d drift. Although the authors do not provide specific data, these various sensors were in patients for from 1 to 12 days in total, and the drift measured immediately after removal of the sensors ranged from –13 to 22 mm Hg. Thus, 6% of catheters that exhibited the high daily drift rate could not have been in a patient any longer than 4 to 7 days.

In actuality, the authors' results demonstrate better performance of this sensor than some of the studies that they quote and, in some cases, better than what the device manufacturer cites as its expected rates: 2 mm Hg for the first day and 1 mm Hg/d thereafter. Thus, one would have expected these authors to find that the 20 catheters that were in the patient for more than 2 days would have a total absolute drift greater than 3 mm Hg, whereas in fact only 50% of the catheters did.

The authors discuss the literature on various other catheters, and this information should be useful for the clinician who is involved in the ICP monitoring of patients with neurotrauma. I take issue with the authors' statement that "a total drift of more than 3 mm Hg is unacceptable." In my opinion, it is more important that the clinician be aware of the limitations of these devices and, when utilizing them, take into account the results of carefully performed studies such as the one presented here.

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This article includes data concerning quality control of the physics aspect of the Camino ICP transducer. The authors assert that 50% of devices that they tested for zero drift had absolute drifts of at least 3 mm Hg. They conclude that this

rate represents an unacceptable tolerance, that there are more reliable technologies in existence for ICP monitoring, and that the Codman sensor is thus no longer optimal technology. To make this assertion, surely the characteristics of these other sensors should have been presented to allow side-by-side comparison. I hope that such a comparison is forthcoming from the group.

In my view, the main conclusion presented is not fully justified by the data presented. Although the authors began with 50 catheters, only 34 were truly assessed for methodological reasons; thus, the sample is quite small. In fact, only 6% of the catheters tested showed a zero drift of 3 mm Hg or more per day during the monitoring. In my view, these drift amounts are very small, and they are not biologically significant. It would be interesting to know how many catheters had greater than 10% overall drift during the entire monitoring period. What is the biological significance of testing for drift at 22°C? The authors do draw attention to the significant problem of a 10% failure rate in these catheters in the "real world" of clinical use. It would be interesting to know how these catheters failed (e.g., kinking, breakage).

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