Continuous monitoring of intracranial pressure with a miniaturized fiberoptic device

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A No. 4 French fiberoptic catheter initially developed as an intravascular pressure sensor was incorporated into a system to be used as an intracranial pressure (ICP) monitor. Initially, a series of acute and chronic animal experiments carried out in the rabbit and pig, respectively, demonstrated the reliability and safety of the device. Subsequently, this new monitor was compared to a concurrently functioning ICP monitor in 15 adult and five pediatric patients. This clinical experience also confirmed the safety, accuracy, and reliability of the device. Since these initial studies, this monitor has been used to routinely measure ICP in a large number of adult and pediatric patients. The monitor has functioned well, and there have been no complications related to its use except for an occasional problem with breakage of the optic fiber as a result of patient movement or nursing maneuvers, which has been easily corrected by replacement of the probe. As nursing personnel and ancillary services have become familiar with this new monitor, breakage has not been a problem. This new device can be placed into the ventricular system, the brain parenchyma, or the subdural space, and appears to offer substantial advantages over other monitors presently in use.

KEY WORDS: intracranial pressure, brain tissue pressure, intraventricular pressure, fiberoptic pressure monitor

INTRACRANIAL pressure (ICP) monitors that are currently in use include ventricular catheters, subarachnoid screws, and various subdural and epidural monitors. All of these devices have recognized advantages and problems. Ventricular catheters are accurate but are occasionally difficult to place in the presence of brain swelling and shift; they may be affected by obstruction or infection as well. Subarachnoid devices are easily placed but can malfunction if they become loose or are not absolutely coplanar to the brain surface. Some authors indicate that these monitors underread at higher pressures. Epidural devices require placement through a burr hole and can be hampered by recording artifacts, dampening, and problems with calibration. In view of this, a No. 4 French fiberoptic probe with the transducer in the tip, initially developed by Camino Laboratories for intravascular pressure recording, has been adapted for use as an ICP monitor (Fig. 1). This device appears to be simple to use and accurate over a clinically relevant period of time. In this study, this monitor is compared to a standard method of ICP recording (namely, ventricular catheter monitoring) in an acute and chronic animal model. In addition, our initial experience in over 100 subsequent patients is reported. This new device appears to have significant experimental and clinical applications and offers substantial advantages over other devices presently in use.

Materials and Methods

Animal Models

Acute Model. All animal experiments were approved by the Animal Use Committee of the University of California at San Diego. Five rabbits were anesthetized, intubated, and placed in a stereotaxic head frame. Evans blue dye was given intravenously. A No. 18 spinal needle was directed stereotaxically into the right lateral ventricle of each rabbit, and the No. 4 French fiberoptic probe was inserted 2 mm deep into the parenchyma of the right parietal lobe 5 mm posterior to the ventriculostomy via a small twist-drill hole. A 1 x 1-cm craniectomy was made over the left frontal region and a balloon-tipped catheter was inserted into the epidural

*Camino 420 OLM intracranial pressure system manufactured by Camino Laboratories, San Diego, California.
Fiberoptic intracranial pressure monitoring

Fig. 1. Photograph showing a No. 4 French fiberoptic probe extending through its housing device. The transducer of the monitor is in the metal tip at the extreme right. To insert the device, a small stab wound is made in the scalp. A 2-mm twist-drill hole is made through the bone, and the housing device is screwed into place. The dura is perforated with a small probe and the transducer probe is threaded through the housing unit as far as necessary and fixed in position by tightening the ring unit over the housing device. The protective sheath is then snapped into place.

The baseline intraventricular pressure and brain tissue pressures were recorded, then the balloon was inflated at the rate of 0.03 cc/min. All pressures were recorded continuously, and the results were noted at 5, 10, 15, and 20 minutes after commencement of balloon inflation. The balloon was then deflated and the animal was rested for 15 minutes. Pressures were then recorded and the balloon was inflated rapidly (0.2 ml/10 sec), with pressures recorded continuously and the results noted at 5, 10, and 20 seconds. The balloon was deflated and the animal was sacrificed. The brain was removed, fixed in formalin, sectioned in the coronal plane, and examined by a neuropathologist in order to detect the presence of any extravasated Evans blue dye. Linear regression curves were used to compare ventricular pressures with brain parenchymal pressures.

Chronic Model. Five pigs, each weighing 20 to 30 kg, were anesthetized with morphine and nitrous oxide. A No. 5 French catheter was placed into the right lateral ventricle of each pig to permit continuous intraventricular pressure recordings. The fiberoptic device was placed 1 cm into the brain parenchyma in the left occipital region, posterior to the ventricular system. The animal was maintained in an anesthetized state for 72 hours. Intraventricular and parenchymal pressures were continuously and simultaneously recorded throughout this period. Approximately 12 hours prior to the end of the experiment, all pigs were infused with Evans blue dye. The animals were sacrificed, and the brains were removed and placed in formalin. The brains were sectioned in the coronal plane and were examined by a neuropathologist to determine the presence of any extravasated Evans blue dye. In addition, all of the fiberoptic probes were checked for drift or damage.

Experimental Results

In the acute animal model there was excellent correlation between the ventriculostomy and the fiberoptic probe at either rapid or slow pressure changes (Fig. 2). The quality of the waveform and the pressures recorded from the fiberoptic probe and intraventricular catheter were essentially identical. In the opinion of the neuropathologist, the brains of the five rabbits showed less injury from the fiberoptic probe than from the ventriculostomy, mainly because of the smaller diameter of the fiberoptic probe.

A typical result using the chronic model in Pig 2 is depicted in Fig. 3. This demonstrates that throughout this period the brain tissue pressure was approximately 3 to 5 mm Hg higher than the intraventricular pressure. Drift upward averaged 1 mm Hg/day. Examination of the brains showed the Evans blue dye extravasation to be less than that induced by the ventriculostomy. No dampening of the system was found in these chronic animal studies.
Human Trial and Clinical Use

Following the animal experiments, and after approval had been obtained from the Human Research Review Committee of the University of California at San Diego, brain tissue pressure recordings were carried out in 15 adults and five children using this device. For these studies the device was used along with a traditional ICP monitor (either an intraventricular catheter or a subarachnoid bolt). A typical brain tissue pressure tracing from one patient is shown in Fig. 4. In all instances the brain tissue pressure was within 2 to 5 mm Hg of the results obtained with the standard monitor, except on two occasions of high pressure when the subarachnoid bolt was considerably dampened and showed lower pressures. No instances of infection or other complications were associated with this device. No catheter was noted to drift more than 1 mm Hg/day, and the drift was always toward higher pressures.

Since completion of the human trial, in which no complications were associated with the use of this monitor, we have used this device as the sole monitor of ICP in various clinical situations. We have now placed it in over 100 adult patients and 20 pediatric patients. The device has been used for variable lengths of time, as clinically indicated. It has been left in place for up to 2 weeks in a few instances and has functioned well. No infections or hemorrhages have been recorded to date. In our clinic, ventricular catheters are changed every 5 to 7 days to avoid infection. Subarachnoid bolts are not changed routinely, nor is the fiberoptic device. The drift was noted to drift more than 1 mm Hg/day, and complications were associated with this device. No catheter was noted to drift more than 1 mm Hg/day, and the drift was always toward higher pressures.

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Fiberoptic monitor has a rapid response rate and correlates well with ventricular pressure acutely and over a clinically relevant time period. In addition, it is easy to place and safe to use. Because the transducer is in the tip, there is no concern about the level of the transducer. Furthermore, this is not a fluid- or air-filled system, and has the advantage of minimizing leaks or drift and reducing the likelihood of infection. Finally, this fiberoptic device also allows direct measurement of brain tissue pressure.

Brain tissue pressure measurements have been used in previous laboratory investigations. Many believe that brain tissue pressure gradients may be important in edema formation and regional capillary blood flow. Unfortunately, the methods used to measure brain tissue pressure in the laboratory have been cumbersome or hampered by technical difficulty. With this new device it is possible to easily record accurate brain parenchymal, subarachnoid, subdural, and intraventricular pressures in a variety of clinical and laboratory settings. It is accurate, has minimal drift and, because it is a self-enclosed electronic system, alleviates problems common to fluid-filled systems.

Discussion

The preliminary animal studies indicated that this fiberoptic monitor has a rapid response rate and correlates well with ventricular pressure acutely and over a clinically relevant time period. In addition, it is easy to place and safe to use. Because the transducer is in the tip, there is no concern about the level of the transducer. Furthermore, this is not a fluid- or air-filled system, and has the advantage of minimizing leaks or drift and reducing the likelihood of infection. Finally, this fiberoptic device also allows direct measurement of brain tissue pressure.

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Acknowledgments

We are grateful to the following individuals for their assistance: Henry C. Powell, M.D., for reviewing the neuropathological specimens; Junichi Ono, M.D., Michael M. Todd, M.D., Sylvia Schneider, and Sue Moore for technical assistance; and Ward Flexer for manuscript preparation and editorial support.

Fig. 4. Brain tissue pressure (BTP) compared to ventricular fluid pressure in a human subject. ICP = intracranial pressure. Asterisk indicates a time when the patient was receiving chest physiotherapy, with blood pressure at 170/110 mm Hg.

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Manuscript received September 29, 1986. Accepted in final form January 30, 1987.

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