Evaluation of a fiberoptic intracranial pressure monitor

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The fiberoptic device is a relatively new type of intracranial pressure (ICP) monitor which appears to offer certain advantages over conventional monitoring systems, particularly its ability to measure brain parenchymal pressures. This study was undertaken to analyze the accuracy and drift characteristics of the fiberoptic device and to compare pressures in the subdural, intraparenchymal, and intraventricular compartments. The device was accurate to ± 3 mm Hg over a 0- to 30-mm Hg range in vitro. The maximum daily drift was ± 2.5 mm Hg, with an average daily drift of ± 0.6 mm Hg and an average drift over a 5-day period of ± 2.1 mm Hg. In vivo, the pressures and waveform characteristics obtained with the fiberoptic device and with a strain-gauge transducer connected to a ventriculostomy were very similar. Alterations in ICP were induced by various therapeutic and pathological manipulations, and the pressures in the three intracranial compartments were compared. Changes in ICP appeared to be reflected simultaneously and equally in all three compartments. Furthermore, changes in ICP secondary to a unilateral mass lesion were identical in both supratentorial parenchymal compartments when measured simultaneously. It is concluded that the fiberoptic device is an accurate and reliable system for ICP monitoring; the pressures recorded in the subdural, intraparenchymal, and intraventricular compartments paralleled each other in all of the physiological and pathological states tested. Although the drift associated with this device is less than that reported for previously available systems, its maximal cumulative drift over a 5-day period of ± 6 mm Hg is significant. Since the fiberoptic device cannot be recalibrated in situ, it is suggested that the device be replaced if monitoring is to be continued for periods longer than 5 days.

KEY WORDS • intracranial pressure monitoring • fiberoptic device • subdural pressure • intraparenchymal pressure • intraventricular pressure

Since the early observations by Monro and Kellie on intracranial volume-pressure relationships, much has been elucidated about the dynamics of cerebrospinal fluid (CSF) and the means by which the intracranial contents make adjustments for volume changes. Much of the recent work in this area has focused upon intracranial pressure (ICP) and the importance of monitoring patients at risk for intracranial hypertension. Improved outcomes have been reported in patients whose ICP was treated when it became elevated above certain levels. Nevertheless, debate continues regarding the risk-benefit ratio and cost-effectiveness of this technique.

Several pressure-monitoring devices have been developed for use in ICP measurement. These devices include epidural and subdural sensors, subarachnoid screws and bolts, and a variety of intraventricular catheters. A relatively new development has been that of the fiberoptic device. This device uses a monitor that senses changes in the amount of light reflected off a pressure-sensitive diaphragm located at the tip of a fiberoptic catheter. Mean pressure is then displayed digitally on the monitor.* This ICP monitor has the advantages of being solid-state and of being effective in the subdural, intraparenchymal, and intraventricular compartments. The first stage of this project was designed to examine the accuracy and drift characteristics of the fiberoptic device. The second stage used an animal model to determine the relationships between pressures in the subdural, intraparenchymal, and intraventricular compartments at baseline and with various therapeutic and pathological manipulations.

Materials and Methods

Three fiberoptic devices were calibrated in the laboratory and remained exposed to the air for 5 days. They

* Digital pressure monitor, Model 420, manufactured by Camino Laboratories, San Diego, California.
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FIG. 1. Diagram showing the laboratory arrangement used in this study. A ventricular catheter was placed in the lateral ventricle and connected to a conventional strain-gauge pressure transducer. Fiberoptic devices were placed in the subdural, intraparenchymal, and intraventricular compartments; the intraventricular device was inserted via a ventricular catheter. A multichannel recorder simultaneously recorded the intracranial pressure from the four monitoring devices.

were then placed in water for five days at depths corresponding to 10, 20, and 30 mm Hg.

In the animal studies, fiberoptic devices were placed in the subdural, parenchymal, and ventricular compartments of five mongrel dogs. The ventricular fiberoptic device was passed through a ventriculostomy containing a Y-connector which allowed the ICP to be measured simultaneously by a strain-gauge transducer similar to the system used clinically (Fig. 1). After 30 minutes, during which the devices were allowed to reach steady state, baseline ICP tracings were obtained from each of the three intracranial compartments. During this time, the tracings were carefully monitored to ensure that each of the fiberoptic devices and the ventriculostomy gave reasonable ICP readings and produced characteristic CSF waveforms. Simultaneous recordings from the three intracranial compartments were obtained during the therapeutic manipulations of hyperventilation, ventricular fluid withdrawal, pentobarbital (10 mg/kg) and mannitol (1 gm/kg) administration, and the pathological manipulations of hyperventilation, ventricular fluid injection, and epidural balloon inflation. In a sixth dog, fiberoptic devices were placed bilaterally into the brain parenchyma. An epidural balloon was introduced in one side and was slowly inflated. Simultaneous ICP waveform tracings were obtained as before.

Measurements of the ICP were recorded prior to and several minutes after the various manipulations. In cases where the manipulation caused an abrupt rise or fall in ICP, an acute ICP value was also obtained. Mean ICP values were calculated from three consecutive ICP waveforms in a fashion analogous to calculating mean arterial blood pressure.

FIG. 2. Graph showing pressure readings from three fiberoptic devices (FOD) at 0, 10, 20, and 30 mm Hg over a 5-day period. Each type of symbol represents pressures recorded from a separate fiberoptic device. Note that drift occurred from above and below actual pressure.

Results

Accuracy and Drift

The accuracy and drift data from the fiberoptic devices is shown in Fig. 2. The devices were accurate to ± 3 mm Hg over a 0- to 30-mm Hg range. The maximum drift over 24 hours was ± 2.5 mm Hg and the maximum drift over a 5-day period was ± 6 mm Hg. The average daily drift was ± 0.6 mm Hg and the average drift over the 5-day period was ± 2.1 mm Hg. When the fiberoptic devices were left exposed to air at the termination of the animal experiments, no device had drifted more than ± 2 mm Hg.

Analysis of ICP Data

The data from the first five animals yielded 112 ICP values from each of the fiberoptic devices and from the strain-gauge transducer connected to the ventriculostomy. The experiment in the sixth animal, to examine the pressure relationships between the brain parenchyma ipsilateral and contralateral to the epidural balloon, yielded 38 ICP values. For the vast majority of the ICP measurements, all of the ICP tracings from the fiberoptic devices and the ventriculostomy corresponded very closely to one another. It was observed that, in the cases where the absolute ICP values differed, the change recorded in response to any particular manipulation was very similar in all of the ICP devices. This observation was believed to be due to vertical height discrepancies between the various catheters, as this would affect the absolute ICP value but not the relative change in ICP seen for any of the manipulations. Therefore, for purposes of comparison, linear regression analysis was used to examine both the absolute ICP values and the relative changes.

Comparison of Fiberoptic Device and Ventriculostomy

The absolute ICP values and relative changes in ICP values obtained from each of the fiberoptic devices
were plotted against the standard (strain-gauge transducer connected to a ventriculostomy) as shown in Fig. 3. The correlation coefficients from the linear regression analysis are shown in Table 1. All of the correlation coefficients obtained from the changes in ICP were better than the absolute ICP value comparisons, thus substantiating the earlier observation. Furthermore, the sizes and shapes of the ICP waveforms obtained from the strain-gauge transducer and fiberoptic devices were very similar.

**Comparison of Intracranial Compartment Pressures**

The fiberoptic device recordings were compared to establish relationships between the subdural, intraparenchymal, and intraventricular pressures. Both the absolute ICP values and ICP changes were plotted. The correlation coefficients are shown in Table 2. Examination of the timing and rate of change of the compartmental pressures revealed that all reacted simulta-
TABLE 1

Pressures recorded with fiberoptic devices located in three intracranial compartments compared with the standard*

<table>
<thead>
<tr>
<th>Intracranial Compartments</th>
<th>Absolute ICP</th>
<th>Change in ICP</th>
</tr>
</thead>
<tbody>
<tr>
<td>subdural</td>
<td>.94</td>
<td>.98</td>
</tr>
<tr>
<td>intraparenchymal</td>
<td>.97</td>
<td>.98</td>
</tr>
<tr>
<td>intraventricular</td>
<td>.98</td>
<td>.99</td>
</tr>
</tbody>
</table>

*The standard was recorded with a strain-gauge transducer connected to a ventriculostomy. ICP = intracranial pressure. Values are correlation coefficients.

TABLE 2

Comparison of pressures in different intracranial compartments as recorded with a fiberoptic device

<table>
<thead>
<tr>
<th>Intracranial Compartments</th>
<th>Absolute ICP*</th>
<th>Change in ICP*</th>
</tr>
</thead>
<tbody>
<tr>
<td>subdural vs. intraparenchymal</td>
<td>.94</td>
<td>.94</td>
</tr>
<tr>
<td>subdural vs. intraventricular</td>
<td>.93</td>
<td>.98</td>
</tr>
<tr>
<td>intraparenchymal vs. intraventricular</td>
<td>.98</td>
<td>.98</td>
</tr>
</tbody>
</table>

*ICP = intracranial pressure. Values are correlation coefficients.

neously and at the same rate to all of the various manipulations. Furthermore, the sizes and shapes of the ICP waveforms between compartments were identical (Fig. 4).

ICP Ipsilateral and Contralateral to an Expanding Epidural Mass

In the sixth animal, the pressure relationship between the brain parenchyma ipsilateral and contralateral to an expanding epidural mass was examined by inserting and slowly inflating an epidural balloon on one side of the supratentorial compartment. The correlation coefficient was .96 for the comparison of the absolute ICP between the ipsilateral and contralateral supratentorial compartments. A similar correlation of .98 was obtained when the changes in ICP between the two compartments were compared. As in the previous comparisons, the plotted data demonstrated a nearly straight-line correlation. The changes in ICP occurred simultaneously and at the same rate bilaterally (Fig. 5).

Discussion

The goal of this study was twofold: 1) to examine the accuracy and drift characteristics of the fiberoptic device and to compare it to the current standard (strain-gauge pressure transducer connected to a ventriculostomy); and 2) to use the fiberoptic device to establish the pressure relationships between the subdural, intraparenchymal, and intraventricular compartments. The latter goal is of great clinical relevance as single-compartment ICP monitoring (such as by subarachnoid bolt or ventriculostomy) assumes that the compartment being monitored is in constant equilibrium with the other intracranial compartments.

The fiberoptic device appeared to accurately measure ICP. In vitro, these devices accurately measured pressure to ± 3 mm Hg over a range of 0- to 30-mm Hg. In vivo, the linear regression analysis indicated a very close correlation between the ICP values obtained from the fiberoptic devices and those obtained from the strain-gauge pressure transducer. In addition, the CSF waveform characteristics recorded using the fiberoptic devices were very similar to those obtained with the conventional pressure transducer system.

Vertical height discrepancies between the devices were certainly present in vivo, even though these differences were small. This finding is consistent with the observation that the relative changes in ICP between devices exhibited a better correlation than the absolute ICP values, since vertical height differences would affect
absolute ICP but not the relative change in ICP. Further minor experimental error may also have occurred when the multichannel recorder was calibrated for each of the devices, and when ICP values recorded graphically from the multichannel recorder were translated into numerical values.

The drift studies indicated that for short-duration ICP monitoring, the fiberoptic device exhibited relatively little drift. By the 5th day, the cumulative drift becomes significant (maximum ± 6 mm Hg, mean ± 2.1 mm Hg). Based on this finding, it is concluded that the fiberoptic device should probably be replaced after approximately 5 days. This may have the additional desirable effect of lowering the incidence of infection, as there is some evidence to suggest that after 5 days there is a significant increase in infection associated with ICP monitoring devices. The inability of this device to be recalibrated in situ remains its principal limitation. Another limitation of the fiberoptic device is that it cannot be used for CSF drainage unless it is used in conjunction with a ventriculoscopy.

Once it was concluded that the fiberoptic device accurately measures ICP and exhibits little drift over short time intervals, the device was then used to examine intracranial compartmental pressure relationships. For all of the acute changes in ICP induced by the various manipulations, the pressures within the subdural, intraparenchymal, and intraventricular compartments responded at the same time, at the same rate, and to the same degree. Likewise, examination of the supratentorial intraparenchymal pressure ipsilateral and contralateral to an expanding epidural mass showed the same ICP on both sides. Similar results have been reported in the clinical setting. Because these observations were made in a canine model, in which the craniospinal axis is smaller and anatomically slightly different from that in man, care should be exercised in directly extrapolating these data to the clinical situation. Although differences in compartmental pressures have been reported by certain groups, the limited information available on supratentorial pressures is contradictory. Weaver, et al., using subarachnoid bolts to measure ICP in four patients, reported higher pressures on the side of mass lesions. However, more recently, Yano, et al., reported no difference in subarachnoid pressures with bifrontal catheters used in 15 patients. Marshall, commenting on the latter paper, stated that studies by his group had shown no difference in pressure in the two supratentorial compartments when ventriculoscopies were used, even though differences were noted when bolts were employed. He suggested that the reported differences in pressure were perhaps a function of the device (in that case, the subarachnoid bolt). While the results of the present laboratory study tend to support the conclusions of Yano, et al., and Marshall, studies using the fiberoptic device in a clinical setting would be very useful in resolving this issue.

The fiberoptic device provides an excellent means of measuring parenchymal pressure. Other methods of measuring parenchymal pressure, utilizing a fluid-filled catheter or wick, have been plagued with the problem of catheter occlusion by such substances as parenchyma or clot, and thus needed periodic irrigation or replacement. Because the fiberoptic device is solid-state, it obviates this problem. This feature can be invaluable in situations where the ventricles are compressed and difficult to cannulate. This device appears to be an accurate and reliable system for ICP monitoring in the subdural, intraparenchymal, and intraventricular compartments. The animal studies indicated that pressures in the subdural, intraparenchymal, and intraventricular compartments are virtually identical in a variety of physiological and pathological states. Furthermore, pressures ipsilateral and contralateral to an expanding epidural mass were almost identical.

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