Intracranial pressure monitoring by flaccid-cuff catheter in an animal model

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Presently available methods of measuring intracranial pressure (ICP) include the intracerebral wick, subarachnoid bolt, epidural monitor, and intraventricular catheter. Each measures one or more parameters of ICP and each has its disadvantages. The wick method has been used for research but has limited value clinically since it measures fluid tissue pressure and responds slowly to acute pressure changes. With increasing ICP, edematous cerebral tissue can occlude the subarachnoid bolt, thus dampening the recorded pressure. Mendelow, et al., found that the subarachnoid bolt underestimated the occurrence of elevated ICP. The epidural monitoring devices may falsely record high pressure because of irregularities in the dura or inner table of the skull. The direct intraventricular line has been most useful because of the ability to withdraw cerebrospinal fluid (CSF) to assist in control of elevated ICP, but masses or generalized increased ICP may compress the lateral ventricle, making insertion of the catheter difficult or impossible.

In 1959, Tarlov, et al., inserted a balloon catheter into cerebral tissue to record pressure changes. They used a small latex balloon attached to a No. 18 needle, and were able to record pressure changes resulting from supratentorial and subtentorial compression in animals. Clark, et al., reported on the use of an unbonded silicone strain gauge half-bridge (designed for cardiovascular monitoring) mounted on a No. 5 French catheter. This device was calibrated in a water jacket and placed in the white matter of the brain. The catheter was found to respond rapidly to changes of ICP in both acute and chronically implanted situations. They considered that their system was useful mainly for rapid phasic changes. The most important limitation was the existence of drift and inability to recalibrate the monitor in vivo.

We have developed a silicone flaccid-cuff (FC) catheter to record ICP changes. The flaccid cuff has the advantage of being easily deformable by minimal pressure alterations.

Materials and Methods

The FC catheter is made of silicone poured over a 4 × 2.5-mm wooden mold and allowed to solidify. Following removal of the silicone cuff from the mold, a polyethylene catheter (1.14 mm in inner diameter and...
Flaccid-cuff monitor for intracranial pressure

1.57 mm in outer diameter) is inserted 2.5 mm into the cuff and secured with silicone cement. The FC catheter is sterilized with Cidex (glutaraldehyde), then washed and filled with sterile saline, taking care to insure removal of all air bubbles. The FC catheter is then placed inside a No. 9 French polyethylene cannula and the device is inserted into the white matter of the brain (Fig. 1). The outer cannula is then withdrawn. At this point the extracranial end of the inner FC catheter is open (so there is only atmospheric pressure on the intracerebral cuff); it is then connected to a Statham low-pressure venous transducer for recording by a Grass polygraph.*

Ten adult cats of both sexes served as subjects for ICP monitoring. After induction of ketamine anesthesia (30 mg/kg), the animals' heads were shaved, scalp incisions were made, and 4-mm holes were placed in the skull with a high-speed drill. The dura was incised with a scalpel, and the FC catheter with its outer cannula was inserted 5 to 6 mm beneath the surface of the cortex as described above. Other lines were placed, including intraventricular catheters, intracerebral balloons to create mass effect, spinal subarachnoid catheters, and arterial lines. Both intracerebral and intraventricular monitors were inserted in three animals; the FC catheter with a balloon catheter was placed in the contralateral hemisphere to act as an intracerebral mass in two; a balloon to produce a mass effect, an intraventricular line on the side of the balloon, and an FC catheter in the opposite hemisphere were placed in one animal; the FC catheter, an intraventricular catheter, and a spinal subarachnoid catheter were inserted in one; and one had insertion of the FC catheter and a spinal subarachnoid line. In two control animals, only the FC catheter was placed. All animals, except the two controls, had placement of arterial monitors.

Two cats were paralyzed with gallamine triethiodide and were ventilated with a Harvard respirator.† The rate of ventilation was varied to change the ICP as recorded by the FC catheter. Two animals had injection of saline into spinal subarachnoid catheters to elevate the ICP, and in two animals intraperitoneal epinephrine was injected in a 1:1000 concentration. In three cats the intracerebral balloon was inflated to simulate a mass lesion. In four cats the volume of fluid in the FC catheter was varied to evaluate the recorded pressures as compared to recordings from an intraventricular catheter in the contralateral lateral ventricle. Three cats had jugular and abdominal compression to alter ICP.

Results

The tracings from the FC catheter were comparable with those of the intraventricular catheters. Each recorded the effects of blood pressure and respirations on ICP in the lightly anesthetized animal (Fig. 2). Jugular vein compression and abdominal compression produced prompt increases in the recorded ICP (Fig. 3). The FC catheter showed a rise in ICP in response to increasing pCO2 by hyperventilation. Intraperitoneal injection of 0.2 cc of a 1:1000 concentration of epinephrine as well as intraspinal subarachnoid injection of 0.2 cc of saline caused a prompt rise in ICP. In the three animals that had insertion of a balloon in the hemisphere opposite the FC catheter, the FC catheter and intraventricular line recorded comparable pressure changes to inflation and deflation of the balloon (Fig. 4). As the balloon was slowly inflated, the animals' pupils became dilated and fixed. The FC catheter revealed an initial rise in ICP, followed by a decrease as the brain became decompressed through the foramen magnum. The respiratory effects on the ICP diminished as the breathing became agonal, and eventually there was total loss of respirations and blood pressure.

In the two control animals, the FC catheters were occluded with bone wax except when pressures were being monitored. High-quality tracings were obtained

* Pressure transducer P23Db manufactured by Statham Instruments, Inc., Los Angeles, California; Grass Model 7 polygraph manufactured by Grass Instrument Co., Quincy, Massachusetts.

† Harvard respirator manufactured by Harvard Apparatus Co., Inc., 150 Dover Road, Millis, Massachusetts.
at 1, 3, and 7 days after insertion of the FC catheter in one animal, and on Days 1, 3, 7, 14, and 21 in the other.

The catheters maintained accuracy and sensitivity as long as the cuff remained flaccid. Withdrawal of all fluid from the catheter resulted in loss of recordable pressure, which could easily be corrected by addition of fluid to partially fill the catheter. Overinflation of the cuff caused an inaccurate elevation of recorded pressure, and, with marked overinflation, sensitivity to ICP change was lost. This could be corrected by evacuating the contents of the catheter and by inserting fluid so the catheter was flaccid but not collapsed.

Pathological examination revealed very few inflammatory cells associated with the device. The brain tissue in the immediate vicinity of the catheter was slightly compressed. With prolonged use of the catheter, an occasional reactive astrocyte could be found. In the control animal with the FC catheter in place for 21 days, a few inflammatory cells were found, including fibroblasts located in the meninges and superficial cortex.
Flaccid-cuff monitor for intracranial pressure

**Discussion**

The flaccid-cuff (FC) catheter has several advantages over other methods of ICP recording. The device is easily inserted into the centrum semiovale via a small hole in the skull. The floppy cuff responds readily to very slight pressure changes, and, with use limited to 72 hours, the risk of brain-tissue reaction and infection should be minimal. We have obtained high-quality recordings in this animal model for up to 21 days without evidence of infection.

As reviewed by Martin,\(^2\) the pressure (P) across the membrane of the catheter depends on the radii and wall tension according to the equation, \(P = T(1/R_1 + 1/R_2)\), where \(R_1\) is the radius along the long axis, \(R_2\) is the radius along the short axis, and \(T\) is the wall tension. With a cylinder, the radius of the long axis is infinity; therefore, \(P = T(1/R_2) = T/R_2\). With any given length \((L)\), \(P = \pi(L)/V\), where \(V\) is the volume of the catheter. Since \(R_2\) and \(L\) are constant for a given catheter, the change in pressure across the membrane varies directly with the change in volume. By calibrating with a known volume of liquid such that \(P = 0\), any deformation of the membrane will be recorded as a change in pressure. As long as the cuff is flaccid and partially filled, there should be no wall tension and \(P = 0\). Even if there is some loss of fluid from the cuff during use, the cuff will still be flaccid and should remain functional. If enough fluid is lost for the catheter to collapse, the tracing will be lost; addition of sufficient saline to partially fill the cuff will return the catheter to a functional state. If there is enough fluid in the catheter so that it remains flaccid, the catheter can be calibrated *in situ*.

The intracerebral pressure recorded by the FC catheter was 1 to 2 mm Hg lower than the intraventricular pressure. This difference was also found by Poll, *et al.*,\(^2\) in a comparison of brain-tissue and intraventricular pressures, but they concluded that the difference was not significant. Our monitor records both tissue-fluid pressure and solid pressure.

**Conclusions**

This study indicates that the FC intracerebral pressure monitor is an effective method of monitoring ICP. The system appears to be accurate, it is easily inserted, and is well tolerated on a short-term basis. The floppy cuff provides maximum sensitivity to ICP changes. It should prove useful under a variety of conditions in which ICP monitoring is required.

**References**


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