Intracranial pressure: measurement and monitoring.
CSF pressure as a ‘golden standard’.
Intraparenchymal pressure. Sensors, drifts, errors and monitoring techniques

Monitoring of CSF pressure: instant manometric CSF column measurement is inadequate

Golden standard: ventricular CSF pressure or Lumbar CSF pressure

Thanks to Dr. DJ Kim
Fluid filled line connected to CSF space (ventricular or lumbar) with external pressure transducer

Advantages:
1. Possible re-calibration and zeroing
2. Possible check of patency

Disadvantages:
1. Risk of infection
2. Low frequency bandwidth
Problems with CSF pressure monitoring through intraventricular catheter

Thanks to Dr. K Aquilina
Microtransducers- early solutions
Figure 3-5 Sites for ICP measurement for brain injury: Iv – intraventricular, Ip – intraparenchymal, Sa – subarachnoid space, Ed – epidural and Sd – subdural

Thanks to Mr P. Hutchinson
ICP MICROSENSOR: Accuracy in its Design

- Microchip Strain-gauge technique: Pressure at the sensor tip results in an electric voltage
- Microchip in the tip is encapsulated in titanium case
- Nylon shaft

Thanks to Ms D. Tangun
Example - diameters and setup

Thanks to Dr. R. Penn
Thanks to Ms. Christele Nardo
Camino® catheter placement

**PARENCHYMAL**
- Bolted system with fiberoptic catheter
- Catheter inserted into brain tissue (1cm)

**SUBDURAL**
- Catheter placed in the subdural space
- May not reflect changes deeper in the brain

**VENTRICULAR**
- Ability to measure ICP and drain CSF
- Catheter placed into lateral ventricle

Thanks to Ms. Christele Nardo
**Principle:**
Transmission of pressure from inside the body to the outside through air.

Partially filled air-pouch transmits pressure to the air-column.

First published by EJ Marey, 1881.

Thanks to Dr. A. Spiegelberg
Colonisation rate of up to 13.2\% in one study investigating 168 fibreoptic probes; 2 patients developed clinically significant ventriculitis at days 10 and 11.


Thaks to Mr.K.Aquilina
Telemetry – early solutions
Long term telemetric ICP monitoring

Intracranial Pressure vs. Time in Asymptomatic Shunted Patients

Thanks to Dr. D.Frim
Rotterdam Transfontanelle ICP transducer

LABORATORY TESTING OF THE PRESSIO INTRACRANIAL PRESSURE MONITOR

OBJECTIVE: The Sophysa Pressio (Sophysa Ltd., Orsay, France) is a new intracranial pressure monitoring system. This study aimed to evaluate its accuracy and compare it with the popular Codman intracranial pressure transducer (Codman/Johnson & Johnson, Raynham, MA) in vitro.

METHODS: A computerized rig was used to test the Pressio and Codman transducers simultaneously. Properties that were tested included drift over 7 days, the effect of temperature on drift, frequency response, the accuracy of measurement of static and pulsatile pressures, and connectivity of the system.

RESULTS: Long-term (7 d) relative zero drift was less than 0.05 mmHg. The temperature drift was low (0.3 mmHg/20°C). Absolute static accuracy was better than 0.5 mmHg over the range of 0 to 100 mmHg. Pulse waveform accuracy, relative to the Codman transducer, was better than 0.2 mmHg over the range of 1 to 20 mmHg. The frequency bandwidth of the Pressio transducer was 22 Hz. The Pressio monitor can transmit data directly to an external computer without the use of a pressure bridge amplifier.

CONCLUSION: The new Pressio transducer proved to be accurate for measuring static and dynamic pressure during in vitro evaluation.

KEY WORDS: Intracranial pressure, Laboratory evaluation, Pressure transducer

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FIGURE 2. Schematic diagram of testing rig. Two transducers, A and B, are sealed in a pressurized chamber, which constitutes a model of cerebrospinal fluid (CSF) space with defined compliance and outflow resistance. The model is submerged in a water bath of controlled temperature. Transducers are connected to monitors (Codman Express and Pressio Monitor) and their differential outputs to bridge amplifiers, providing analog signals for analog-to-digital converter of control computer. Pressure in the chamber may be controlled by a static water column, a pressure waveform calibrator, or an infusion pump mimicking the CSF infusion test.
24-hours time drift

Comparison of 3 microtransducers (A-Camino, B-Codman, C- Fiberoptic Ventrix)

Figure 2  Example of the drift of Camino (upper) and Spiegelberg monitors (bottom) over 24 hours.
**Temperature drift of Camino transducer**

Systematic overestimation of intracranial pressure measured using a Camino pressure monitor

The Camino fiberoptic intracranial pressure (ICP) monitor (Camino Laboratories, San Diego, CA, USA) was the first intraparenchymal microtransducer to be used widely in clinical practice. Recent laboratory tests have confirmed its excellent accuracy and low long term drift when temperature remained constant. However, an increase in ambient temperature pro-

Figure 1  (A) Recording of ICP during removal of a Camino transducer from the subarachnoid space of patients with head injury. The transducer was removed at time point 1. Readings were unstable for about three seconds and then the pressure drift from 4 mm Hg (starting at time point 2) to 0 mm Hg was recorded during cooling of the catheter tip to room temperature. (B) A similar effect to point A was recorded during removal of a Camino transducer submerged in a cylinder filled with warm water (36°C). The pressure decreased (time point 1) from around 25 mm Hg (height of water column) over one second to 0 mm Hg. It is hypothesised that this deeper than expected decrease is caused by an immediate cooling during evaporation of the water from a wet membrane—too small to cool the whole catheter tip. It is repeatable and is probably equivalent to the period of “unstable reading” seen in A. The pressure then increased to 5 mm Hg (at time point 2) and subsequently decreased gradually to 0 mm Hg over the next 20 seconds.
Static and dynamic accuracy of transducer can be measured in laboratory.

**Figure 3.** Bland-Altman plot comparing pressures measured with a water column and readings of the Pressio transducer.

**Figure 4.** Static comparison of the two transducers ($R = 0.999; \text{ slope } = 0.996$).

**Figure 5.** Frequency characteristics of the Pressio transducer relative to the Codman transducer.

**Figure 6.** Relationship between pulse pressure of high amplitudes (20 mmHg) measured by both transducers.
ICP is related to body posture
Normal ICP in horizontal (left) and in sitting up position (right)
Statistics: 63 non-shunted patients
CSF versus intraparenchymal pressure

Lumbar [mmHg]

Tissue [mmHg]
Phase shift between lumbar pulse and parenchymal pulse

Lumbar [mm Hg]

Tissue [mmHg]
What intraparenchymal microsensor really measures

Pressure in water- scalar
‘Pressure’ in brain- tensor
A Study of Perioperative Lumbar Cerebrospinal Fluid Pressure in Patients Undergoing Acoustic Neuroma Surgery

Figure 1. Example of time trend of CSF pressure recorded before and after surgery. Gaps in the recording were caused by transfer of the patient between wards and unreliable pressure recording due to a kinked catheter.
Monitoring through EVD versus intraparenchymal probe

Fig. 2. Time course of intracranial pressure in a patient as measured using a ventricular catheter ($ICP_{vc}$, upper part) and an intraparenchymal transducer ($ICP_{ip}$, lower part), respectively. While the ventricular drainage is opened (left side), periods of increased $ICP_{ip}$ occur, whilst $ICP_{vc}$ remains constant. However when closing the drainage system (right side), $ICP_{vc}$ and $ICP_{ip}$ are showing a parallel time course with almost identical values.
Various forms of focal venous sinus obstruction in the transverse sinuses of 4 patients. Intrinsic filling defects are obvious in the top two radiographs being an arachnoid granulation (A) and a broad based undulating lesion (B). Of the lower two, the radiograph on the left (C) could be a focal stricture or extrinsic compression while the radiograph on the right (D) appears to indicate secondary venous sinus compression or irregularity due to old thrombus.

Coupling between ICP and Sagittal Sinus Pressure – investigated in Idiopathic Intracranial Hypertension

Thanks to Prof. JD. Pickard
Correlation between baseline pressures
Relationship between slow waves of Pcsf and Pssss (at baseline)
ICP monitoring artefacts. Tracheal suction

![ICP monitoring artefacts graph](image)
Coughing

mmHg

ICP
Fig. 1. Preoperative (left) and postoperative (right) graduated electric manometric Queckenstedt test results for Case 6. Trace C is the cuff pressure and Trace L is the lumbar pressure. Cuff inflation was repeated with the neck in the extended (EX, upper), neutral (N, center), and flexed (FL, lower) positions. Asterisk = cough; dot = abdominal compression. Preoperatively, no block was demonstrated with the neck in the extended position, although complete block was evident in the flexed position (left). This block was resolved with the neck in any position following posterior fossa decompression (right).
Summary

• Manometric lumbar assessment may be misleading
• Definition: ICP= CSF pressure in ventricles measured in horizontal position
• Variations: Intraparenchymal pressure, lumbar CSF pressure, transfontanelle pressure
• Intraparenchymal transducers measure vector of force not pressure!
• Advantages: long term stability, low infection risk
• Sagittal sinus pressure: always stable?
• ICP depends on body posture and activity
• Artefacts: mainly dependent on changes in venous pressure