

# New fontanometer for continuous estimation of intracranial pressure in the newborn

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**SUMMARY** Intracranial pressure was estimated by a new pneumatic applanation fontanometer in babies in intensive care. A close correlation with cerebrospinal fluid pressure was found on 35 separate occasions. In 12 control babies the mean (SD) fontanelle pressure was 5.2 (2.2) cm H<sub>2</sub>O, in eight with a hypoxic-ischaemic encephalopathy it was 12.6 (4.3) cm H<sub>2</sub>O, and in nine with post-haemorrhagic hydrocephalus it was 10.8 (4.3) cm H<sub>2</sub>O. In four babies monitored continuously over seven days the correlation remained good. The fontanometer enables pressure to be monitored accurately, continuously, and non-invasively in neonates at risk of raised intracranial pressure.

Several techniques for non-invasive monitoring of intracranial pressure in the newborn through the anterior fontanelle have been described over the past decade. The devices used have been either handheld or strapped to the fontanelle.<sup>1-7</sup> The force of application used to hold or secure these devices to the scalp, however, can distort the fontanelle and lead to a variable overestimate of the intracranial pressure.<sup>3 4 8</sup> Difficulty in achieving stable fixation to the anterior fontanelle has made continuous monitoring of intracranial pressure unsatisfactory. There have been problems with the calibration of the devices and also with a variable zero offset in the pneumatic fontanometers. Lastly, the size of some devices has precluded their use in neonates with small fontanelles. We have designed a new pneumatic applanation fontanometer to overcome these difficulties and have compared the result obtained with direct cerebrospinal fluid (CSF) pressure measurement.

## Patients and methods

The body of the fontanometer is made from a semi-flexible thermoplastic by injection moulding and measures 10 mm in diameter and 4 mm in depth. A schematic section is shown in Figure 1 and a diagram of the whole intracranial pressure measuring system in Figure 2. Three ports are provided: port 1 for gas flow in, port 2 for pressure measurement, and port 3 for gas escape. A thin, compliant polymer membrane is cemented to the perimeter of

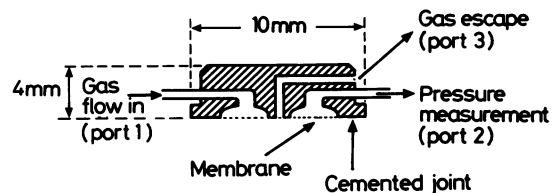


Fig. 1 Schematic section through the transducer body (for detailed description see text).

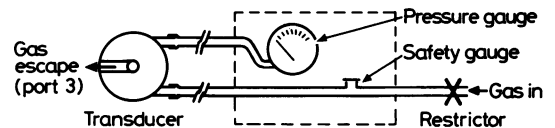


Fig. 2 Schematic layout of the intracranial pressure monitoring system (for detailed description see text).

the base of the body. This initially occludes port 3 and thus a simple valve is formed. A small annular flange allows easy fixation of the body to the fontanelle by applying a thin film of industrial collodion over this flange and around the transducer body. Gas, usually air, is delivered at a constant low flow rate of 0.02 l/min, through a restrictor device, to the transducer at port 1. The gas enters the space surrounding the central escape port 3. Port 3 is initially occluded by the fontanelle pressure acting externally on the membrane, but as the air flow continues the pressure in this space rises and eventually equals the fontanelle pressure, where-

upon the membrane lifts off the escape port 3, and air flows to the atmosphere. The system is now in equilibrium, and the pressure in the space surrounding port 3 is measured at port 2. Port 2 is connected by a 2 mm polyvinylchloride tube to a sensitive low pressure manometer. There is no gas flow through port 2, so the manometer accurately records the transducer pressure, thereby eliminating any zero offset. When the system is in equilibrium the pressure measured at port 2 is equal to the fontanelle pressure. Figure 3 shows the device securely applied to the fontanelle with collodion. In most babies it is possible to perform an ultrasound scan without disturbing the fontanometer. In those with a small anterior fontanelle it can be removed easily by dissolving the collodion with acetone.

The fontanometer was validated in 29 babies by comparing the result with the direct cerebrospinal fluid (CSF) pressure obtained on 35 separate occasions, 26 at lumbar and nine at ventricular puncture. The babies could be subdivided into three main groups, and their characteristics are shown in Table 1. There was a control group of 12 infants who were undergoing lumbar puncture as part of a screen for infection within the first few days of life. None had meningitis or an abnormal cerebral ultrasound scan. Eight babies were studied who presented with seizures within 48 hours after birth and who were

suffering from a hypoxic-ischaemic encephalopathy. CSF specimens were obtained from the eight babies for culture and the pressure measured at lumbar puncture. Nine preterm infants with post-haemorrhagic hydrocephalus were studied when CSF pressure was measured and evidence of craniospinal communication sought. In four without such communication the CSF was drained therapeutically by ventricular puncture. Direct lumbar or ventricular pressure was measured by a simple empty manometer attached to the spinal needle by a three way tap. Free flow of CSF was obtained before and after the pressure measurement. For lumbar puncture the babies were in a straight horizontal position without excessive flexion or restraint. Evidence of craniospinal communication was confirmed by Queckenstedt's test. It was assumed that with normal anatomy the lumbar and spinal subarachnoid spaces communicate freely and that the lumbar CSF pressure reflects the intracranial pressure. The oscillations of the column of CSF in the manometer tubing with heart beat and respiration were observed and a few seconds for equilibration



Fig. 3 Fontanometer applied with collodion to the anterior fontanelle of a baby with a gestational age of 26 weeks.

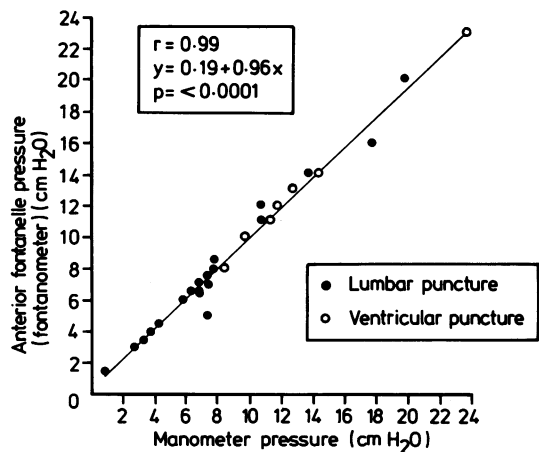


Fig. 4 Correlation of intracranial pressure measured with the fontanometer on the anterior fontanelle with simultaneous direct measurements from lumbar puncture (n=26) or ventricular puncture (n=9).

Table 1 Characteristics of the three groups of babies included in the study. Values are mean (SD) [range]

	Group		
	Control	Hypoxic-ischaemic encephalopathy	Post-haemorrhagic hydrocephalus
(n)	(12)	(8)	(9)
Gestation (wks)	33.1 (5.6) [27-42]	39.8 (1.4) [38-42]	27.3 (2.0) [24-31]
Birth weight (g)	1893 (1094) [570-3460]	3429 (326) [3115-3985]	1025 (303) [789-1673]

Table 2 Mean (SD) [range] pressure measurements obtained in the three groups of babies by a new pneumatic applanation fontanometer and from direct cerebrospinal fluid specimens

	Group		
	Control	Hypoxic-ischaemic encephalopathy	Post-haemorrhagic hydrocephalus
Fontanelle pressure (cm H <sub>2</sub> O)	5.2 (2.2) [1.5-8.0]	12.6 (4.3) [8.0-20.0]	10.8 (4.3) [6.0-23.0]
Direct pressure (cm H <sub>2</sub> O)	5.4 (2.4) [1.0-8.0]	12.9 (4.7) [8.0-20.0]	10.9 (4.4) [6.0-24.0]

allowed before the lumbar and fontanometer pressures were recorded. To investigate the reliability of the fontanometer intracranial pressure was monitored continuously over seven days in four babies without disturbing the device. The results obtained were compared with serial direct pressure measurements during that time.

### Results

Cardiac and respiratory pulsations transmitted through the fontanelle to the device were seen as fine oscillations of the manometer needle throughout the period of monitoring on every occasion. Good correlation was obtained between the fontanometer estimation of intracranial pressure and the CSF pressure measured directly at simultaneous lumbar or ventricular puncture. Figure 4 shows the correlation and regression equation of measurements obtained from the fontanometer and at simultaneous lumbar or ventricular puncture on 35 separate occasions. The correlation coefficient between fontanometer and lumbar CSF measurements of intracranial pressure was good ( $r=0.98$ ,  $y=0.19+0.96x$ ,  $p<0.0001$ ,  $(n=26)$ ). The correlation between fontanometer and ventricular measurements of intracranial pressure was also good ( $r=0.99$ ,  $y=0.12+0.96x$ ,  $p<0.0001$ ,  $(n=9)$ ). The mean pressure measurements obtained in the three groups of babies are shown in Table 2. In the group with post-haemorrhagic hydrocephalus three babies with arrested ventricular dilatation had pressures between 6 and 7 cm H<sub>2</sub>O, whereas the remaining six babies in this group (with progressive ventricular dilatation) had a fontanelle pressure of 10 cm H<sub>2</sub>O or more. In the four babies studied continuously the fontanometer correlated well during the seven days ( $r=0.98$ ,  $y=0.14+0.96x$ ,  $p<0.0001$   $(n=12)$ ).

### Discussion

This new applanation fontanometer when securely fixed to the anterior fontanelle of neonates with both normal and abnormal neurology gives an estimate of intracranial pressure that correlates closely with direct CSF pressure measurement. No

loss of reliability was found with continuous monitoring over seven days. The design overcomes the problem of zero offset, which is responsible for the unreliability of a similar pneumatic fontanometer,<sup>6</sup> by separating pressure measurement from the continuous gas flow. An excessive force of application and the interference with nursing procedures caused by various holding devices is avoided by fixation with collodion.<sup>2-4 7 8</sup> This new fontanometer is also easy to manufacture and cheap.

The mean intracranial pressure estimated by this fontanometer in the control group was lower than that quoted by workers who used other devices, handheld or strapped to the fontanelle,<sup>1-4 7 9</sup> but is in agreement with direct CSF pressure measurements made in a similar population.<sup>10</sup> Rises in intracranial pressure in babies with a hypoxic-ischaemic encephalopathy have been shown before,<sup>3 4 7 11</sup> and similarly we have confirmed that babies with progressive post-haemorrhagic hydrocephalus often have raised intracranial pressures,<sup>3 4</sup> whereas when ventricular dilatation is static the CSF pressure is within the normal range.<sup>10</sup> The good correlation obtained between the fontanometer and CSF pressure measurements in babies with post-haemorrhagic hydrocephalus and also in the term infants with a hypoxic-ischaemic encephalopathy enables those babies developing such problems to have continuous non-invasive pressure monitoring without resorting to invasive techniques, with the accompanying hazards.<sup>11 12</sup> Information about changes in intracranial pressure can now be obtained in a wide range of neonates and the efficacy of the various therapeutic manoeuvres that are commonly used to lower intracranial pressure<sup>3 4</sup> may now be evaluated safely and accurately.

MJR is supported by the Spastics Society. We thank the nursing and medical staff of the intensive care nursery and Mr P Goddard of the biomedical engineering unit for their help.

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Received 26 August 1986

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## Thirty years ago

### The nephrotic syndrome in early infancy

*H McC Giles, R C B Pugh, E M Darmady, Fay Stranack, and L I Woolf (London and Portsmouth)—Arch Dis Child* 1957;**32**:167-80

Thirty years ago congenital nephrosis was less clearly defined as a separate entity from idiopathic nephrosis than it is today. Three infants with this disorder were described. Two were brother and sister, and their parents and paternal grandparents were first cousins. The parents of the third patient, a boy, were second cousins once removed. The common clinical features included oedema, heavy proteinuria, and hypoalbuminaemia, which were noted at birth or by 6 weeks of age. The serum cholesterol was markedly raised in the two siblings. All three infants died before the age of 6 months.

The most striking postmortem findings were in the histology of the kidneys:

(i) The predominant lesions were in the renal tubules, especially in the cortex, with severe dilatation of the lumen and flattening or hyperplasia of the lining cells, and with vacuolation, cloudy swelling, or hyaline droplet degeneration of the epithelium. Glomerular damage was minimal and thought probably to be secondary.

(ii) Microdissection of the kidneys revealed that the first part of the proximal tubule was replaced by a long and narrow neck lined by thin and flattened epithelium. The remainder of the proximal tubule was ballooned and considerably wider than normal.

(iii) Doubly refractile crystalline material was found in alcohol fixed tissues (liver, bone marrow, spleen, and kidney). Its identity or importance was unknown. The pattern of the aminoaciduria in all three infants and the absence of significant glycosuria, however, excluded cystine storage disease.

The authors concluded that all three infants suffered from the same basic disorder and that inheritance as an autosomal recessive characteristic could well explain its occurrence. On the basis of the histological appearances the renal changes were thought to be consistent with "nephrosis", using the term in the sense of a primary tubular disorder.

**Comment.** It seems very probable that the cases reported in this paper fall into the so called Finnish type of congenital nephrosis. While tubular dilatation is pronounced, electron microscopy has revealed that the primary defect lies in fusion of the glomerular foot processes. Prenatal diagnosis is now possible in affected families by showing excess  $\alpha$  fetoprotein in liquor amnii between 14 and 18 weeks' gestation. The disease itself remains uniformly fatal unless the unfortunate infant is submitted to bilateral nephrectomy and thereafter kept alive by peritoneal or haemodialysis until a renal transplant is practicable.

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