Cerebrospinal space
Brain ‘lump in a box’? Compensatory role of lumbar space

Thanks to Dr.O.Baledent
Anatomy of cranial CSF spaces
Volume of brain = 1400 ml

Volume of CSF = 150 ml

CSF in ventricles around 25 ml

Volume of blood = 150 ml

Brain does not ‘float’ in CSF
Role of CSF: ‘mechanistic’- cancelling pressure gradients
: ‘metabolic’ ???

Total volume of cerebrospinal fluid (adult) = 125-150 ml
Total volume of cerebrospinal fluid (infant) = 50 ml
Turnover of entire volume of cerebrospinal fluid = 3 to 4 times per day
Rate of production of CSF = 0.35 ml/min (500 ml/day)
pH of cerebrospinal fluid = 7.33 (from Kandel et al., 2000, p. 1296)
Specific gravity of cerebrospinal fluid = 1.007
Color of normal CSF = clear and colorless
Volume of CSF in ventricles may change

Ventricular volume 25 ml

Ventricular volume 127 ml
Cerebrospinal fluid (CSF) is secreted by the epithelial cells of the choroid plexuses. These cells like those of other secretory epithelia are polarised so that the properties of their apical membrane (ventricle facing) differ from those of the basolateral membrane (blood facing). Both membranes have a greatly expanded area (apical membrane is made up of numerous microvilli, and the basolateral membrane has many infoldings), so that the total area available for transport is similar to that of the blood-brain barrier.
Sites of choroid plexi: pink- lateral ventricles, green- 3rd and 4th ventricles; red- chorid plexi
CSFprod = Infusion \((\text{Ci-Co})/\text{Co}\)
CSF circulation

Lateral ventricles

IIIrd ventricle

Aqueductus C

IVth ventricle

Cisterna Magna

Lumbar CSF space

Subarachnoid space

Sagittal sinus
Components of resistance to CSF outflow

\[ R_{csf} = R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7 = \sum R_s \]

Equation 3-3

Figure 3-13 The resistance of the CSF outflow is the sum of total resistances, which include at the foramina of Munro, the aqueduct, the foramen of Luschke and magendie, the subarachnoid spaces of the infra- and supratentorial regions, the tentorial notch, and the arachnoid granulations of the venous sinuses. Multiple resistances at the various regions of the CSF pathway may cause hydrocephalus. In addition, the degree and the location of a resistance increase may determine the treatments associated with the different types of hydrocephalus. \(^{83}\)
CSF flow in lumbar space
Constant versus pulsatile CSF flow

Ventricles

Arteries

Veins

Intracranial Subarachnoid spaces

Lumbar subarachnoid space

compliant dural Sac

Young brain

aging brain

Thanks to Dr. O. Baledent
The heart, origin of the Cerebral hydrodynamic

Monro-Kellie relation: the volume inside the cranium is **CONSTANT**.

Thanks to Dr. O. Baledent
MATERIAL AND METHODS

Data Acquisition

Scanner: 1.5 Tesla General Electric Healthcare
Sequence: Retrospectively-gated Cine phase-contrast
Cardiac synchronization with peripheral gating
TR: 30 ms  TE: 12-17ms
FOV: 160x120 mm
Matrix: 256x128
Section thickness: 5mm
Flip angle: 30°
Acquisition of 32 cardiac phases

The acquisitions parameters result of a compromise between time acquisition, Signal Noise Ratio and spatial an...
METHODS

Data Analysis

Cervical CSF flow intensities during 32 phases representing a cardiac cycle

Cervical CSF flow level:
Velocity encoding: 5 cm/sec

Dynamic flow images were analyzed on dedicated software, developed on site, based on an automatic segmentation algorithm of region of interest. The algorithm uses the temporal evolution of the intensities to extract those which correspond to the cardiac frequency. Balédent et al. Investigative Radiology 2001

Thanks to Dr. O. Baledent
Fundamental component

image

Flush peak flow

Caudal flow

Cranial flow

Flush peak flow

CSF flow at C2-C3 level

Peak flush V (mm/sec) 43
Tflush (% of cc) 25
Tflush (ms) 252
Peak fill V (mm/sec) -37
Tfill (%) 80
Tfill(ms) 794
Peak-flush-F (mm3/s) 3065
TD_flush (%) 25
TD_flush (ms) 252
Peak-fill F (mm3/s) -1231
TD_flush (%) 80
TD_flush (ms) 794

The software was developed with *Interactive Data Language* (IDL)

Thanks to Dr. O.Baledent
Aqueductal CSF curve flow

Thanks to Dr. O. Baledent
Blood and CSF flows
Mean and standard deviation from 44 healthy volunteers

Cerebral blood flow: 633 ±126 ml/min

Thanks to Dr. O. Baledent
Population studies

- 44 Healthy volunteers

Arterial peak flow propagation

- 5% of cardiac cycle (cc) later:
  - Cervical CSF peak flush: 2.5 ml/sec
  - Jugular blood peak flush: 13 ml/sec
  - Ventricular CSF peak flush: 0.2 ml/sec

Ventricular CSF flow represents only 11% of cervical CSF flow less than 2% of arterial flow.

Brain Equilibrium Pressure: 25-35% of cc later

Thanks to Dr. O. Baledent
Absorption of CSF into sagittal sinus
Davson’s equation
CSF pressure = $p_{ss} + R_{csf} \times I_{formation}$

CSF hydrodynamic studies in man

2 Normal hydrodynamic variables related to CSF pressure and flow

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SUMMARY With the patient in the supine position, the subarachnoidal space was infused with artificial CSF at several constant pressure levels. The resulting flow of liquid was recorded. By draining CSF at a low pressure the CSF production rate was determined. Normal values are given and discussed for (1) the resting pressure, (2) the conductance of the CSF outflow pathways, (3) the formation rate of CSF, (4) the pressure difference across the CSF outflow pathways, and (5) the sagittal sinus pressure. None of the variables showed any age dependence, nor was there any sex difference.

Fig. 1 Example of the relation between pressure and flow obtained in a patient aged 64 years, considered to be “normal”. Abscissa: the CSF pressure obtained when the flow at each level has stabilised after the initially higher flow rate. Ordinate: the corresponding inflow of artificial CSF from the bottle to the patient’s subarachnoidal space. There is obviously a rectilinear relation between pressure and flow which is also true in the majority of all other recordings made. The regression line of flow on pressure, the conductance of the CSF outflow pathways (G₀p), has been calculated according to the formula given in the text. The horizontal line below the abscissa represents the CSF formation rate of 4.6 mm³ s⁻¹ obtained in this patient. The intersection of this line with the regression line thus represents the pressure that should have existed if there were no production of CSF and thus no outflow through the arachnoidal villi—that is, the pressure of the CSF recipient, mainly the sagittal sinus. Below this pressure no elimination of CSF can occur. For further information, see Ekstedt (1977).
Rcsf - resistance to CSF outflow; units mmHg/(ml/min)

Normal resistance 4-10 mmHg/(ml/min)

In hydrocephalus, resistance is increased to > 13 mmHg/(ml/min)

Is it always constant?
Fig 2. Scales for conversion of other units of measurements to SI units and reverse. The 5–95% normal limits for the variables are indicated. The relation between conductance (G) and resistance (R) is: G = 1/R.

CSF hydrodynamic studies in man

2 Normal hydrodynamic variables related to CSF pressure and flow

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Age dependence of cerebrospinal pressure–volume compensation in patients with hydrocephalus

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Fig. 1. Graph demonstrating the relationship between Rcsf and age in patients presenting with symptoms of hydrocephalus. The best-fit model is inverse: $y = 1/(a - bx)$. 

Fig. 3. Graph showing the relationship between CSF production and patient age. In hydrocephalic patients, the estimated CSF production rate is inversely proportional to age.
Arterial hypotension decreases RCSF (17% per 50 mm Hg)

Vascular components of cerebrospinal fluid compensation


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Early experimental works—rabbits-Rcsf increases with hypercapnia (27-48 mm Hg; 18%)

Possible intraparenchymal CSF absorption

CSF

Disrupted ependyma

Entry to parenchyma

Mixing with extracellular fluid

Flow in perivascular spaces

Lymphatic nodes- extracranial
Lymphatic drainage of the brain and the pathophysiology of neurological disease

Roy O. Weller · EYe Djuanda · Hong-Yeen Yow · Roxana O. Carare

Fig. 6 Diagram of the proposed route for lymphatic drainage of the brain. Interstitial fluid and solutes drain from the brain parenchyma into the basement membranes of capillaries and then along the basement membranes between smooth muscle cells in the tunica media of arteries. ISF and solutes then enter the adventitia around leptomeningeal arteries and continue through the base of the skull along the carotid artery (and probably the vertebral artery) to cervical lymph nodes. A layer of pia-arachnoid separates the adventitia of the leptomeningeal arteries from the CSF in the subarachnoid space (SAS)
CSF pressure dynamics

Professor Anthony Marmarou
Contribution of CSF and vascular factors to elevation of ICP in severely head-injured patients

Vascular component = F1(arterial inflow) + F2(venous outflow)

Sagittal Sinus Pressure (3-8 mm Hg). Is it always coupled to CVP?
Idiopathic intracranial hypertension: Simultaneous measurement of ICP and pressure in venous sinuses
A nonlinear analysis of the cerebrospinal fluid system and intracranial pressure dynamics

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A mathematical model of the cerebrospinal fluid (CSF) system was developed to help clarify the kinetics of the intracranial pressure (ICP). A general equation predicting the time course of pressure was derived in terms of four parameters: the intracranial compliance, dural sinus pressure, resistance to absorption, and CSF formation. These parameters were measured in the adult cat, and the equation was tested by comparing experimental and calculated values of the time course of pressure in response to volume changes. The theoretical and experimental results were in close agreement, and the role of each parameter in governing the dynamic equilibrium of the ICP was determined. From this analysis, dynamic tests were developed for rapid measurement of CSF formation, absorption resistance, and the bulk intracranial compliance. These techniques are applicable to clinical settings, providing data that are useful in characterizing the physiological mechanisms responsible for raised ICP and assessing changes induced by therapy.

KEY WORDS - intracranial pressure - compliance - mathematical model - cerebrospinal fluid system

Fig. 1. The CSF system was depicted by an equivalent electrical circuit that distributed the CSF parameters among three fundamental mechanisms: formation, represented by a constant current generator; storage, represented by a nonlinear capacitance (C); and absorption represented by resistance element (R). The venous outflow site (dural sinus) was represented by a constant pressure source P_d. The system equations were derived from this configuration.
Model of CSF circulation
(A. Marmarou 1973)-few contemporary modifications

Intracranial pressure-volume compensation:

MONRO-KELLY DOCTRINE


V_{brain} + V_{blood} + V_{csf} = \text{const}
Message to take home:

- CSF Formation = Absorption + Storage
- Sagittal sinus pressure is not necessarily constant
- CSF flow: DC and AC components
- CSF pressure = $R_{out} \cdot CSF_{formation} + P_{ss} +$ Vascular component?
- Brain does not float in CSF (Volume Brain:CSF = 10:1)
- CSF equalize pressure in brain compartments