All Forms Of Hydrocephalus Can Be Explained By Derangements of Bulk Flow

30 Years of Research Driven By A Bulk Flow Model

There is no such thing as "communicating" hydrocephalus

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Stimulus to Study Pathophysiology of Hydrocephalus

- Bering
- Di Rocco
- Kaufman

- Removal of choroid plexus from model of hydrocephalus led to that ventricle being smaller
- Augmentation of intraventricular pulsation led to hydrocephalus in experimental animals
- Post-Shunt ventricular asymmetry due to damping of pulse pressure by shunt

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Pulsatility

- These three sets of experiments implicated augmentation of the pulse wave as extremely important in the pathophysiology of hydrocephalus
- All three postulated that the choroid plexus was the source of the pulse wave that led to the hydrocephalus
- In all three the systolic pulse would lead to outward displacement of the ventricular wall when the choroid plexus distended

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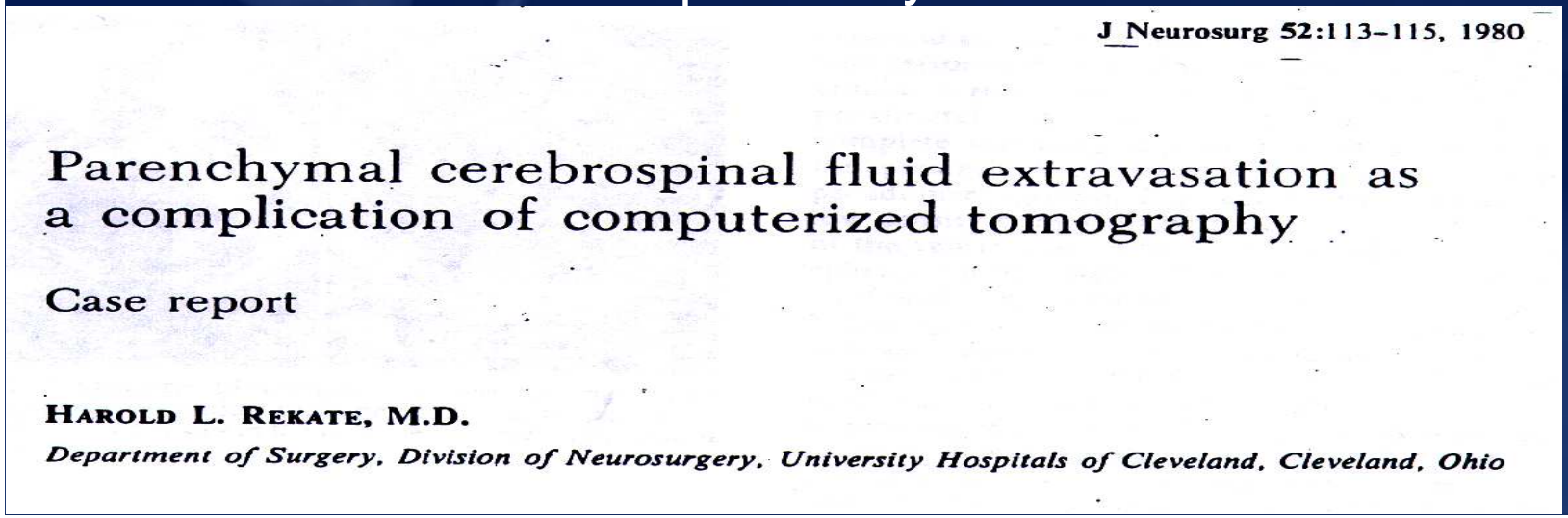
Early Observations And Experiences

- The horror of acute shunt failure in the face of small ventricles and no ventricular access in the Pre-CT era
- The finding that a patient was going blind from increased intracranial pressure with normal tiny ventricles that I had assured the family that the shunt was working
- The finding that if the ependyma is breeched CSF can be forced into the parenchyma



J Neurosurg 52:113–115, 1980

Parenchymal cerebrospinal fluid extravasation as a complication of computerized tomography

Case report

HAROLD L. REKATE, M.D.

Department of Surgery, Division of Neurosurgery, University Hospitals of Cleveland, Cleveland, Ohio

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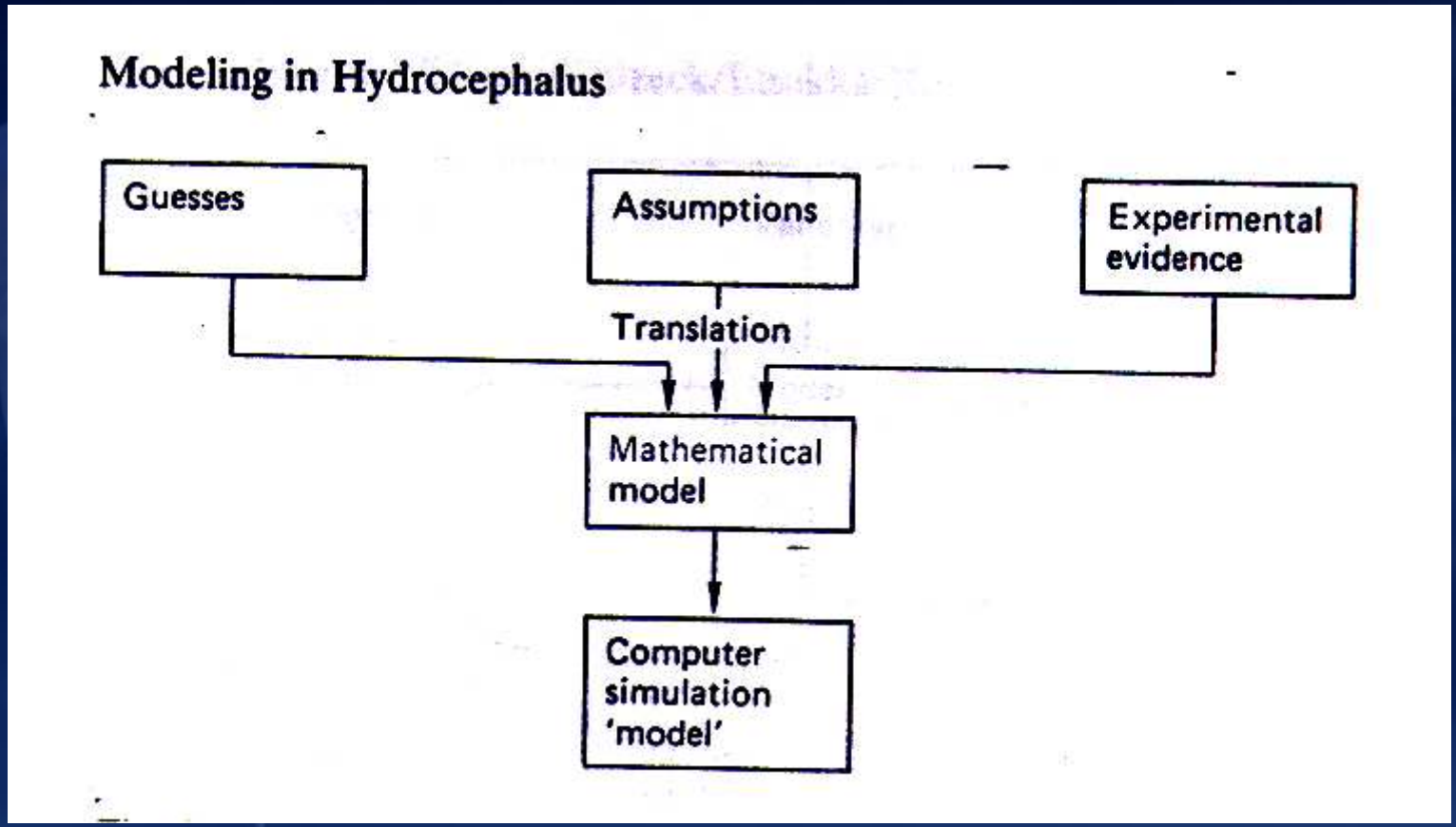
Construction Of The Model



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What Does A Model Do?

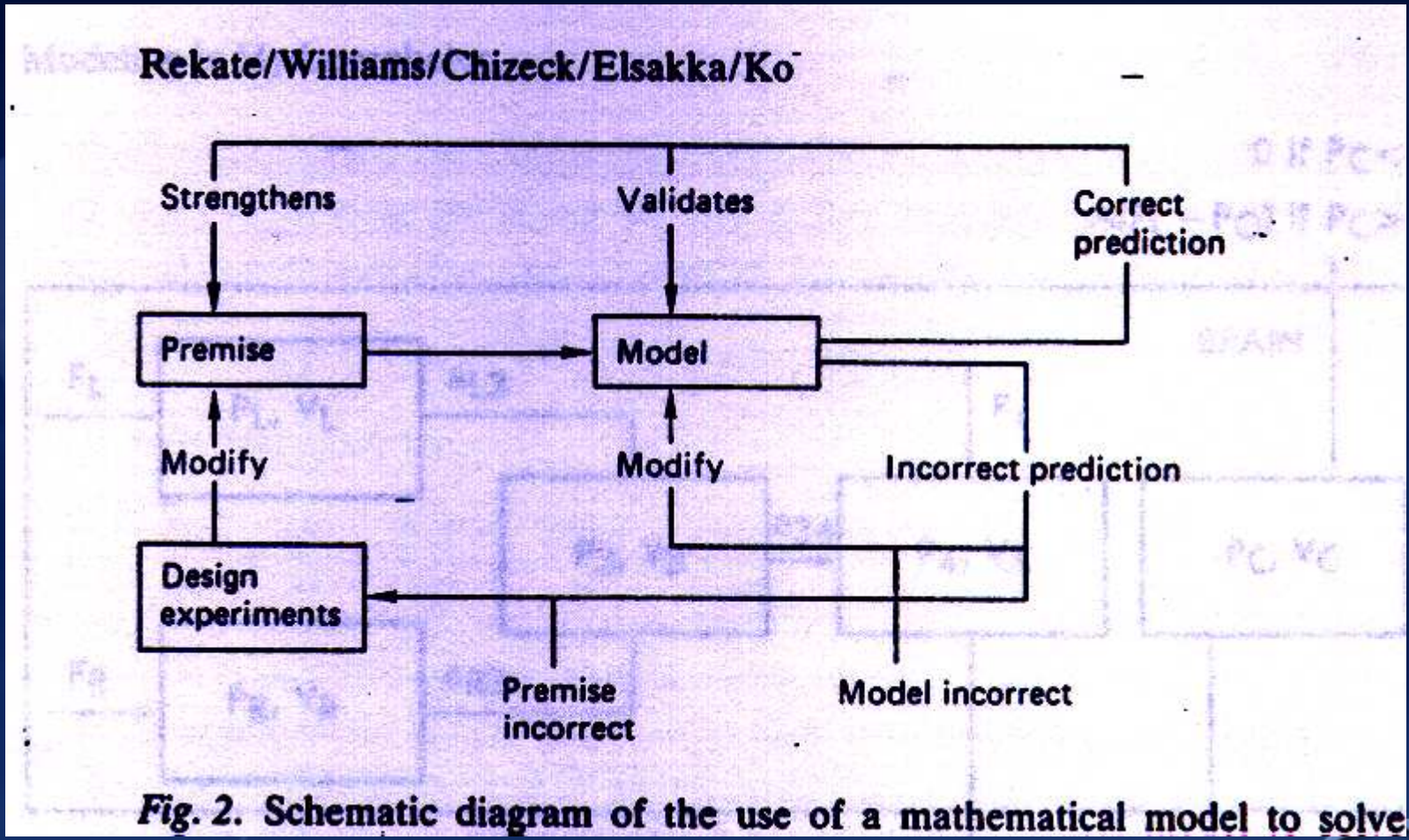

Fig. 2. Schematic diagram of the use of a mathematical model to solve

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Value of Mathematical Models

- Mathematical descriptions of what happens
- Should lead to accurate predications of what will happen next
- Tool of inductive reasoning
- Need to be challenged rather than supported in order to strengthen the value
- Mathematical equations can be produced that will describe the interaction of any measurable quantities.
- “What do you want it to say?”

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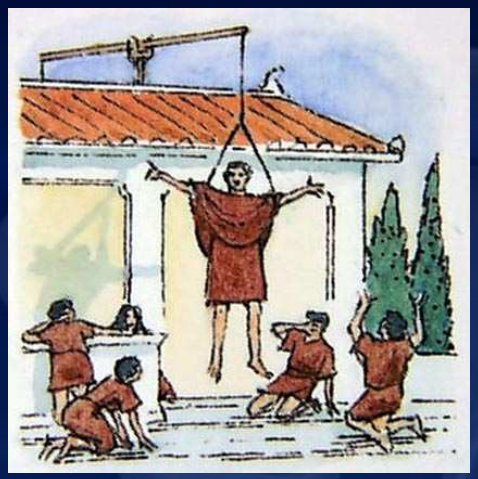
From An Editor's Perspective



- Assumptions based on inadequate understanding of the pathophysiology: I. E. "communicating hydrocephalus"
- Deus Ex Machina
- Inability to define the problem to be solved with the model
- Over short periods of time hydrocephalus causes reversible distension not destruction

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Requirements Of The Model

- Incorporates what is known about the anatomy and physiology of the CSF pathways
- Reliably predicts behavior of ventricular volume
  - In pseudotumor cerebri
  - In Normal Pressure Hydrocephalus
- Useful in developing and analyzing physiologic experiments that will validate the model and provide a better understanding of the pathophysiology of hydrocephalus

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Why A Bulk Flow (DC circuit) Model?

- Several examples of well thought out bulk flow models already existed (Spertell)
- The mathematics of a DC hydraulic circuit are a great deal simpler than that of an AC circuit. The original model was thought to be a first start which would eventually lead to a better understanding of the role of pulsatility in the pathophysiology of hydrocephalus
- The bulk flow model lent itself to more straightforward laboratory experiments and clinical observations than did the pulsatility models
- We had the tools

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Creation Of The Model

- Hydraulic Equivalent Of Ohm's Law
- CSF produced at the rate of 0.33 cc/min
- ICP averages 10 mmHg and is pulsatile
- There are a number of natural restrictive elements within the system that lead to natural compartmentalization
- The brain reacts passively to changes in ventricular volume
- The brain is a viscoelastic substance
- The skull constrains the system
- The spinal subarachnoid space is outside of the constraint and can change in volume without affecting the other volumes.

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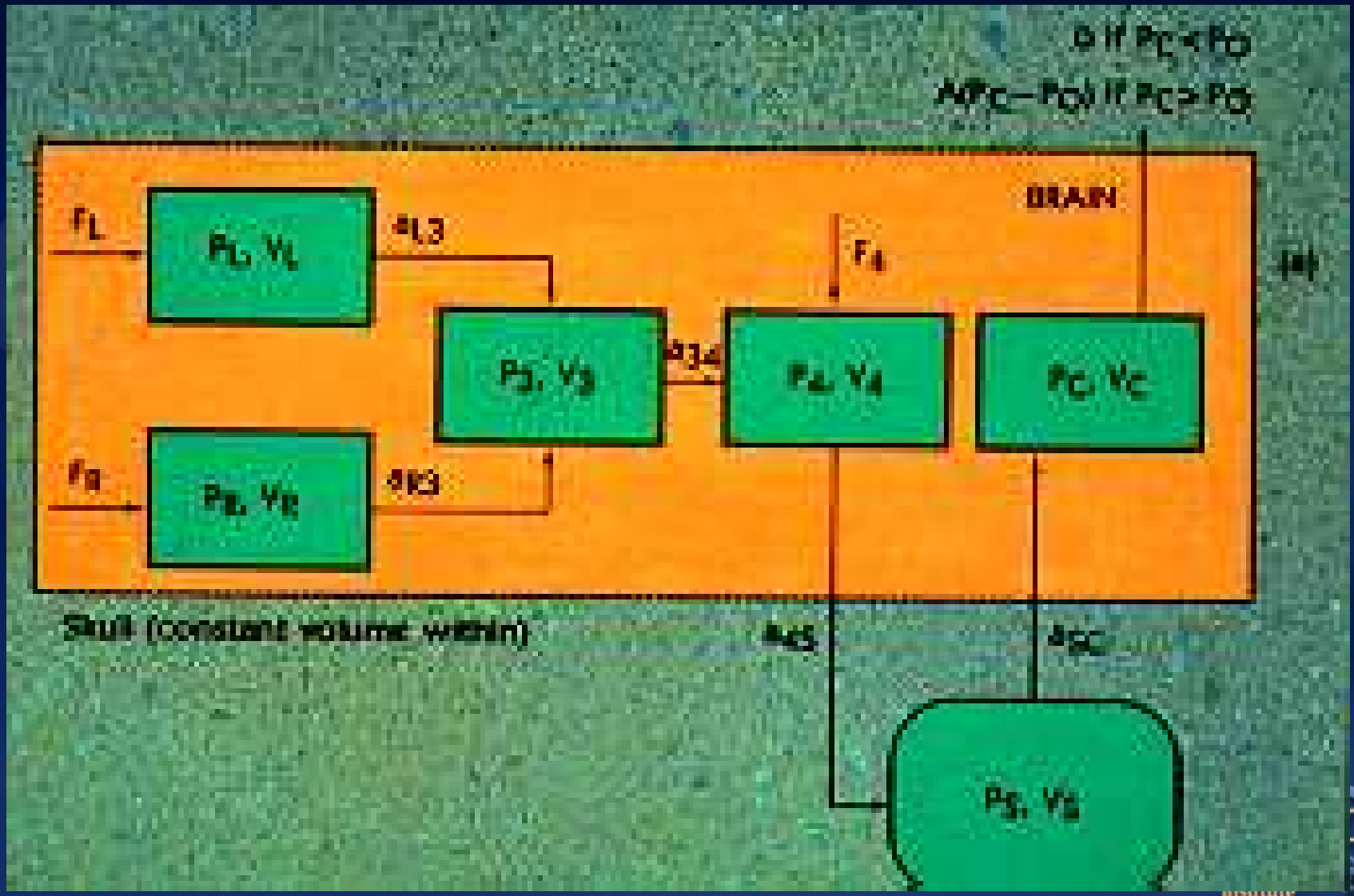
SCHEMATIC



Ro1 NS22901

- First Application denied: Studied the long-term effects of shunting on the brain itself. Were there chronic changes that led to shunt dependency? Rejected as undoable.
- Second application after early development of mathematical model we were using the mathematical model to study the biophysics of ventricular volume regulation: Not high enough priority due to difficulty in actually measuring ventricular volume solved with “black box model.”
- Third application funded and led to many of the articles that you have before you.

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Analysis Of The Role Of The Choroid Plexus In Generating Hydrocephalus

- Experimental Design:
- Normal Greyhound dogs instrumented with ICP monitor and intraventricular balloon
- Stereo speaker covered with water proof sealant
- Wave-form generated exactly 180° out of phase with the ICP pulse wave
- Damps the pulse wave to near flat line

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Results

- Volume required to overcome the intrinsic intraventricular pulse wave 2-3 orders of magnitude greater than can be explained based on the erectile volume of the choroid plexuses plus the per pulse production of CSF
- The intraventricular pulse wave is a product of the pulsatility of the brain rather than the choroid plexus
- Where does that leave us with Bering and Di Rocco?

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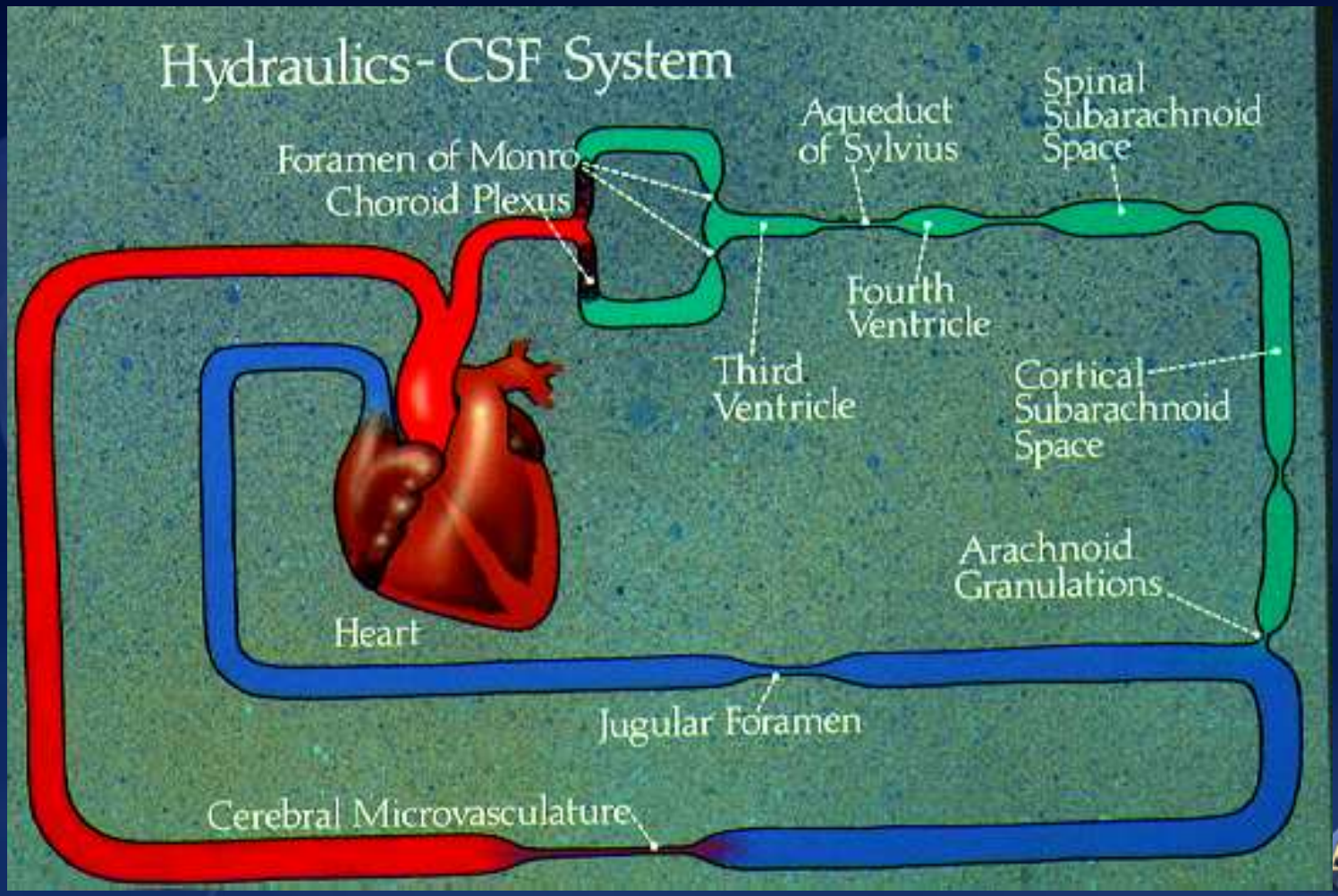
BIOPHYSICS OF THE CSF



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Defining The Resistors Within the CSF Pathways

Foundations of Pediatric Neurosurgery

Articles of interest taken from the series of monographs entitled *Concepts in Pediatric Neurosurgery* are reproduced exactly as they appeared at the time of their publication. These papers represent the materials presented and discussed at past meetings of the American Society of Pediatric Neurosurgeons.
The original article is followed by the senior author's commentary and update.

Pediatr Neurosurg 1994;21:248–253

From: Concepts in Pediatric Neurosurgery 1989, vol. 9, pp 46–56:

Circuit Diagram of the Circulation of Cerebrospinal Fluid

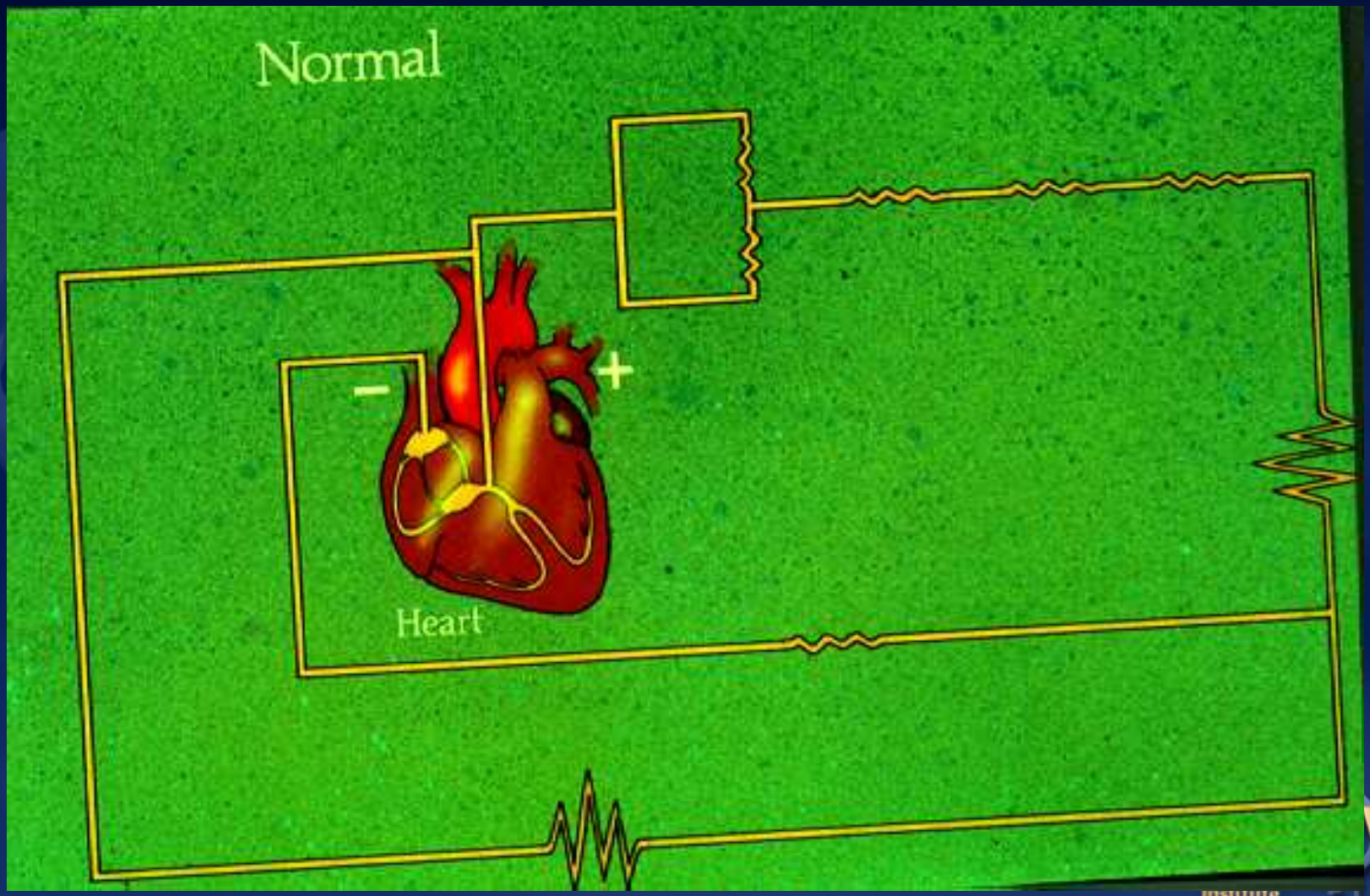
Outflow of Cerebrospinal Fluid

Alfren Benzon Symposum

Resistance Elements within the Cerebrospinal Fluid Circulation

Harold L. Rekate, William M. Olivero, John McCormick, Howard J. Chizeck[1] & Wen Ko[1]

RESULTS OF THE STUDIES



Ventricular Volume Regulation

- Mathematical model with computer simulation
- Requirements
  - Explained recognized patterns of CSF absorptive abnormalities
  - Normal Pressure Hydrocephalus
  - Pseudotumor Cerebri
- Needed a factor to describe resistance to ventricular dilatation

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Explaining NPH and PTC

- The standard hydraulic model would not explain these two enigmatic conditions
- There must be something different with respect to the viscoelastic properties of the living brain that would allow for the observations for these two conditions
- In order to get the model to work and to explain these phenomena we developed a “fudge factor” for the viscoelastic properties so that the computer simulation would work
- Originally thought of as a “Brain Constant” or Kb
- Importance of cortical subarachnoid space

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Investigating The Nature Of Kb

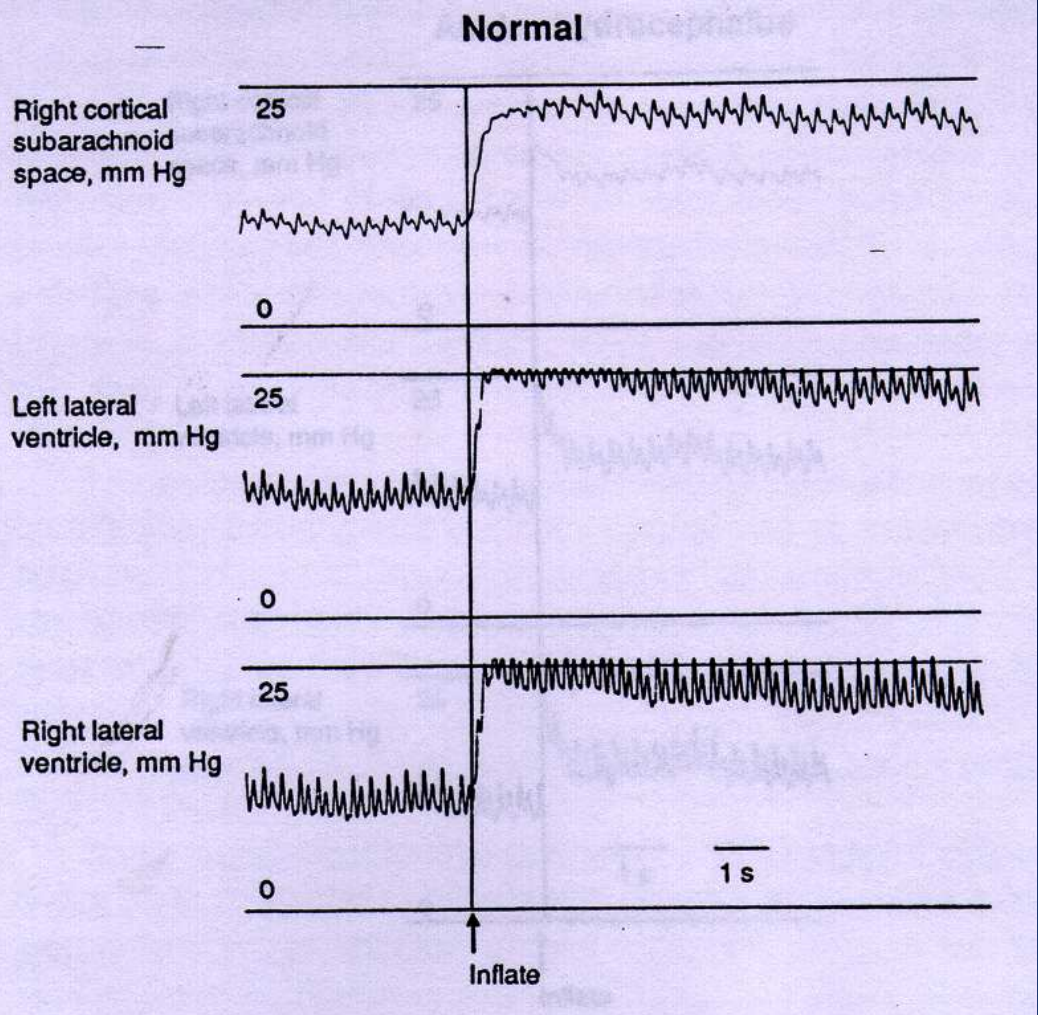
Concepts in Pediatric Neurosurgery
Editor: A.E. Marlin, San Antonio, Tex.

Reprint
Publishers: S. Karger, Basel
Printed in Switzerland

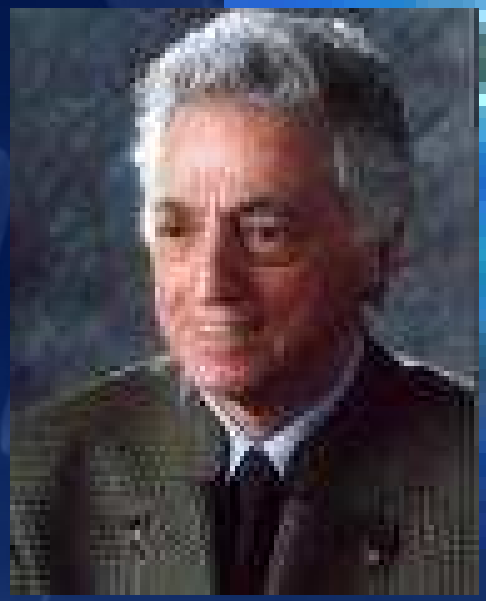
Marlin AE (ed): Concepts Pediatr Neurosurg. Basel, Karger, 1990, vol 10, pp 235–242

Failure to Demonstrate a Brain Transmissibility Factor

Harold L. Rekate[a], *John McCormick*[a], *Wen Ko*[b]



Hal, Your Research Is Very Interesting But Will It Ever Help Anyone?



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Clinical Relevance

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Lumbar Drainage

- Studied extensively in Children and adolescents
- Used only when there is no mass lesion found
- In retrospect most patients found to have cisterns present
- Accesses larger reservoirs of CSF
- Increases CPP

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LUMBAR DRAINAGE

- No evidence of herniation
- Despite the fact that all patients were refractory to all forms of therapy including barbiturate coma in the early cases, there were no cases of herniation
- Outcome shows that half of the patients are in normal school environments and none are vegetative.

Levy, et. al. J. Neurosurg. 83:453-60, 1995

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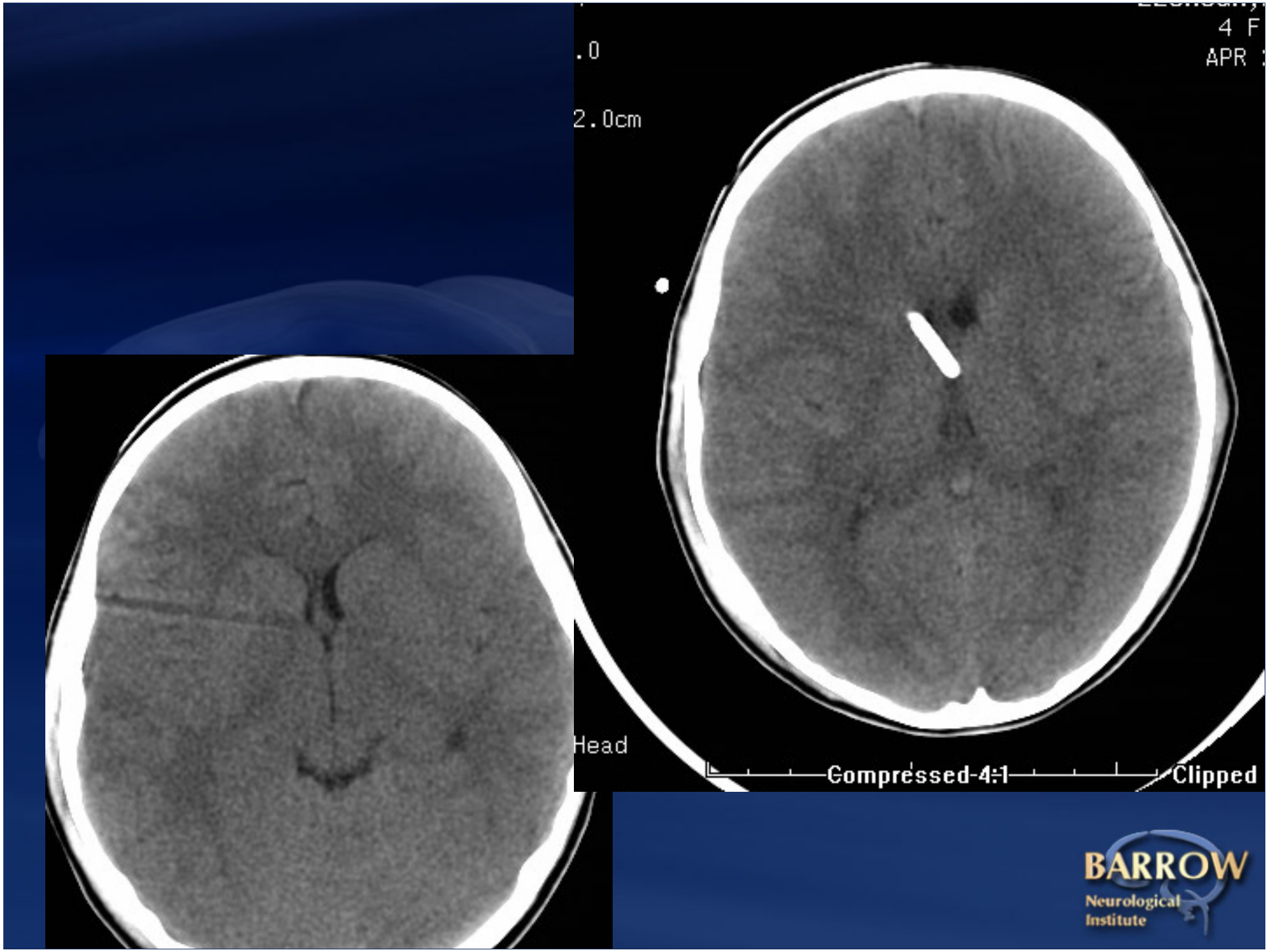
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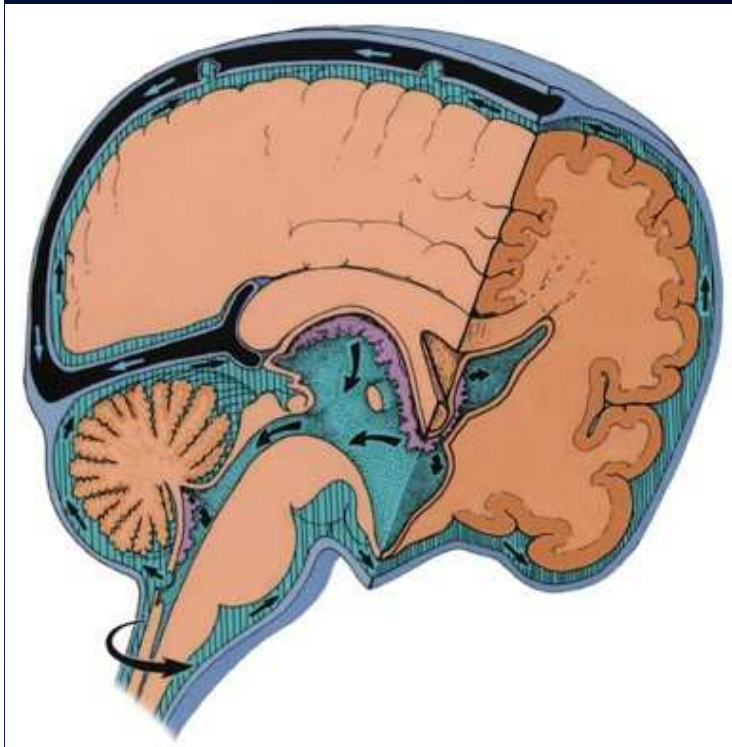
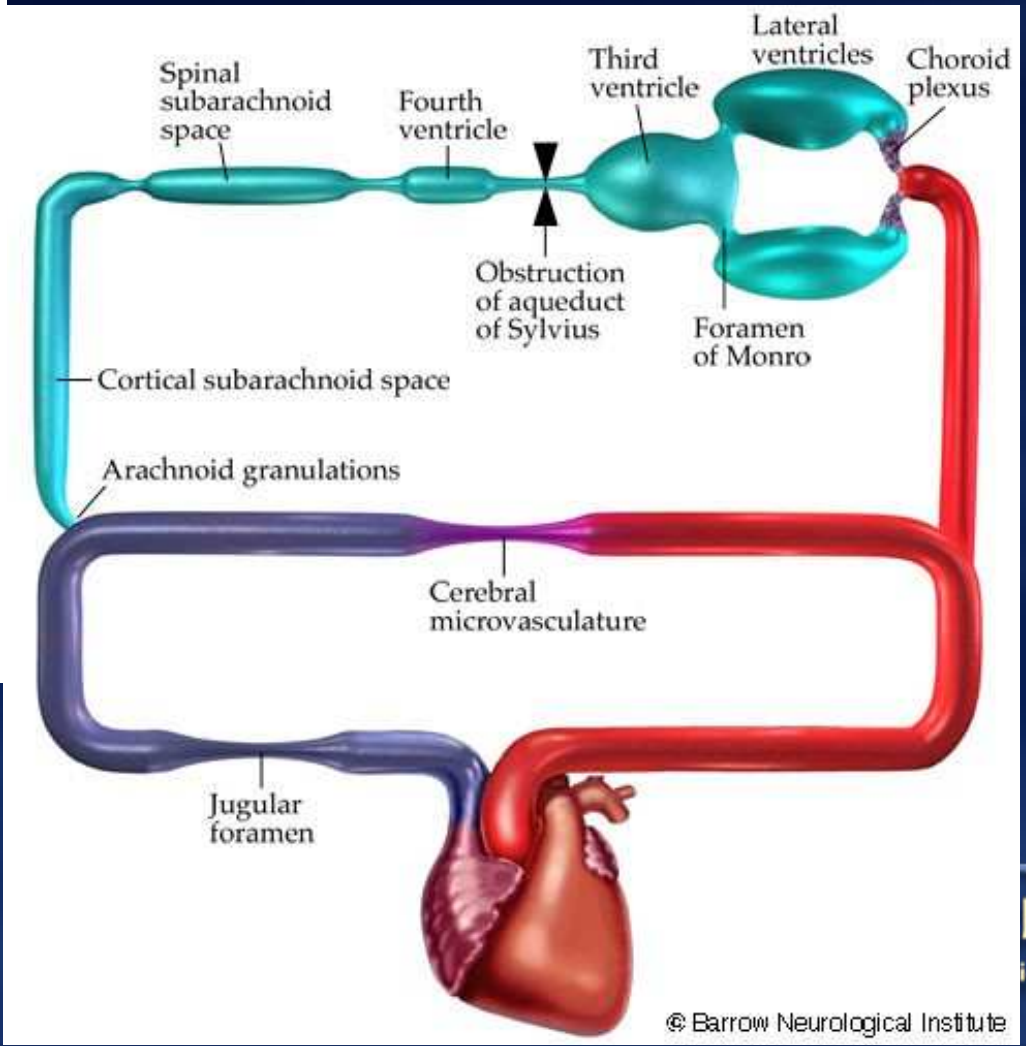
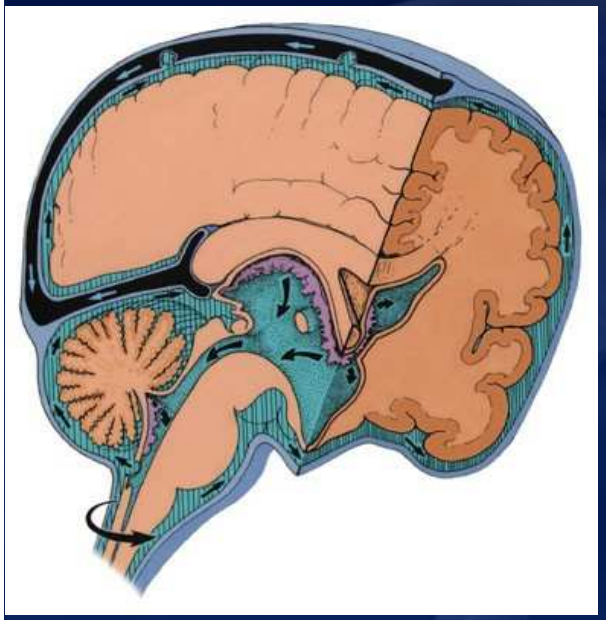
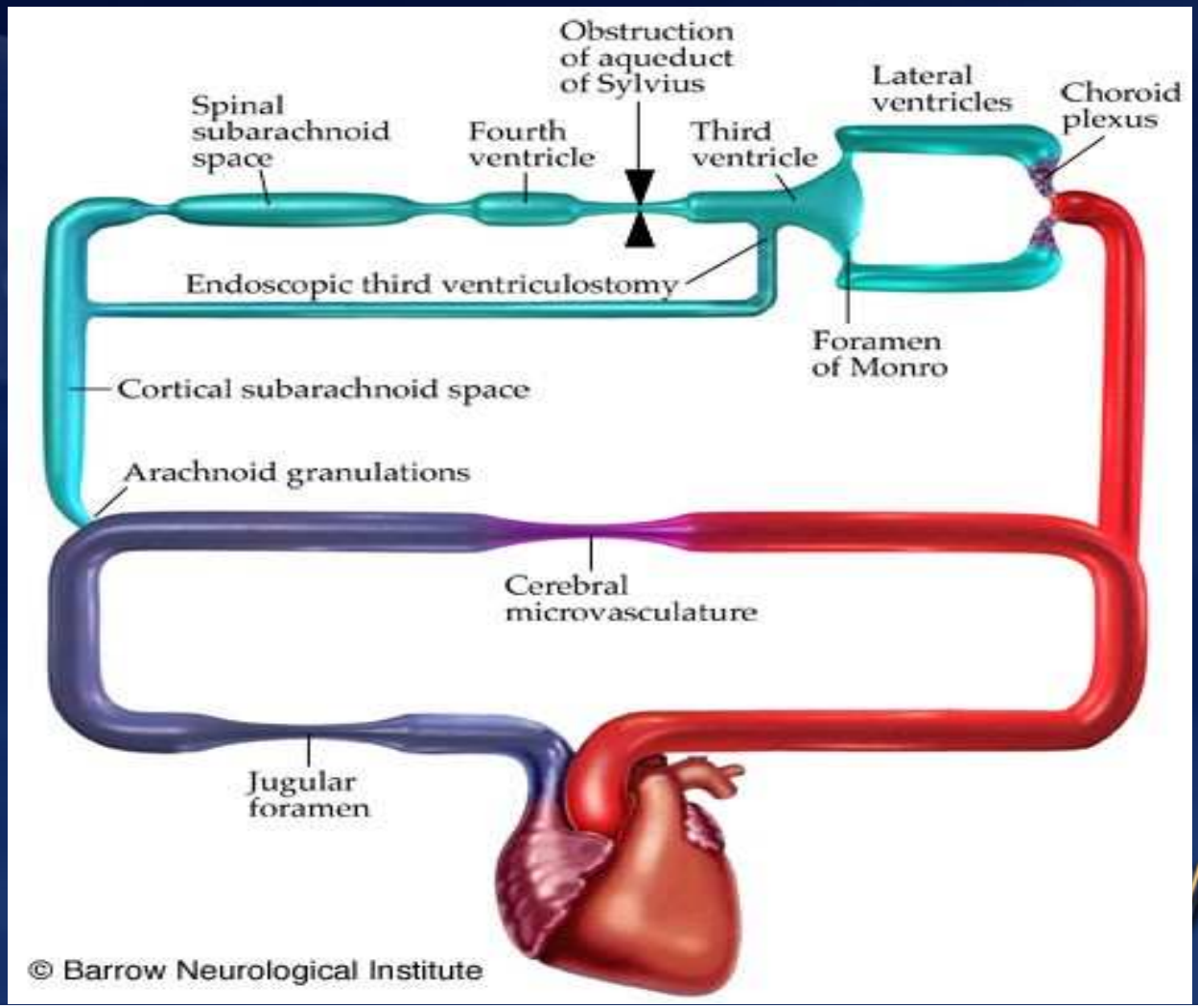
What Is "Communicating Hydrocephalus"





What Is An Endoscopic Third Ventriculostomy





CONCLUSIONS

- Guidelines book should lead to good prospective trials of efficacy and position of “second tier therapies”
- Lumbar drainage appears in our hands to be safe in patients who have cisterns and no mass lesions
- Barbiturate therapy may lower ICP but often at the cost of CPP

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Conclusions

- Defining the point of obstruction in hydrocephalus leads to improved decision making
- It is easier to define the point of obstruction after the initial treatment has been done.
- Treatment should be individualized for each individual

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Non-Responsive Ventricles

- Due to shunt related pseudotumor
- Unless there has been a severe intercurrent infection all non-responsive ventricles are “communicating”
- Best treated by accessing the cortical subarachnoid space.
- Cranial expansion is only a temporary fix.

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Clinical Papers Based on Model

- Elevated Intracranial Venous Pressure *pseudotumor*
- Ventricular Shunt Removal
- Adults with Hydrocephalus Treated in Infancy
- Lumboperitoneal Shunts In Children
- Classification of Slit Ventricle syndromes
- Selection of patients for endoscopic third ventriculostomy

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"Rekate's Rules" For The Management Of The Difficult Shunt

- All compartments containing CSF must communicate with each other
  - Endoscopic fenestration
  - If you need multiple catheters they need to be spliced above the valve
- Even though the shunt has the same settings or description they are never the same and different valves or non-communicating areas change volumes at different rates
- Recumbant pressure 5-15 mmHg
- Erect pressure -5 to +5 mmHg

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Define Importance Of Pulsatility

- Original NIH grant application included treatment of hydrocephalus with a shunt to a closed balloon
- Gary Magram's "Accumulator" shunt
- What happens with CSF abdominal pseudocyst or pleural effusion with pleural shunts
- Is there clearance of CSF in the ventriculosubgaleal shunt?

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Why Can't We Work Together?

- The energy brought to the system with CSF pulsatility brings 2-3 orders of magnitude more energy than that produced by bulk flow
- Possibly except for the problem of CSF overproduction of CSF in Choroid plexus papillomas and the experiments of Di Rocco and Bering every problem related to hydrocephalus can be explained by restriction of CSF flow and has been documented to involve increases in R0
- "Don't throw the baby out with the bathwater"
- Loss of brain tissue is a very late result of hydrocephalus and most cases have early, complete reconstruction of cerebral mantle

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