Neuromechanics and Neurosurgery -Inseparable!

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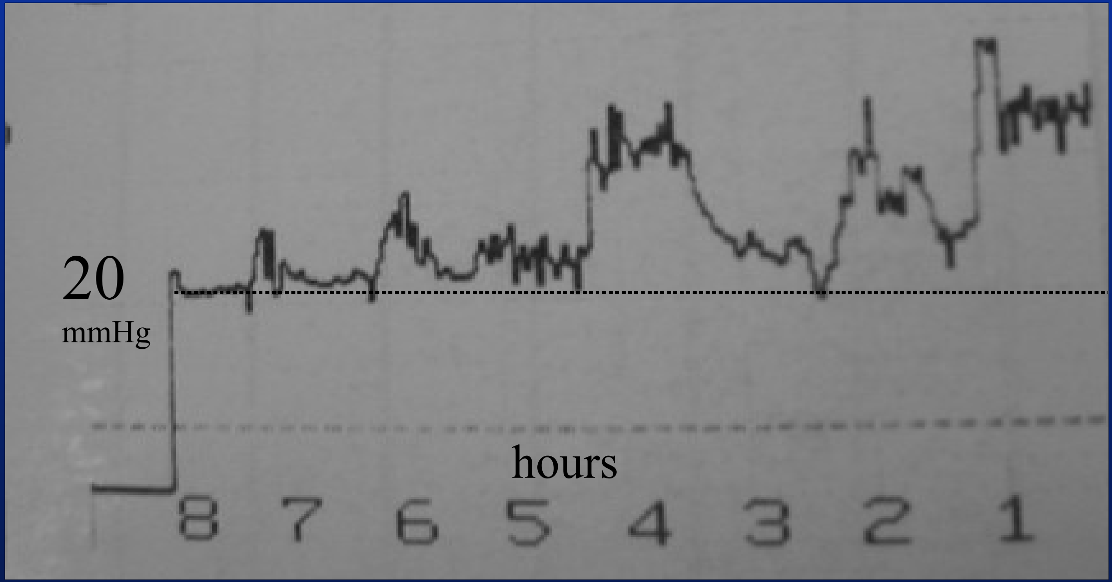
University of Toronto, Canada

SickKids

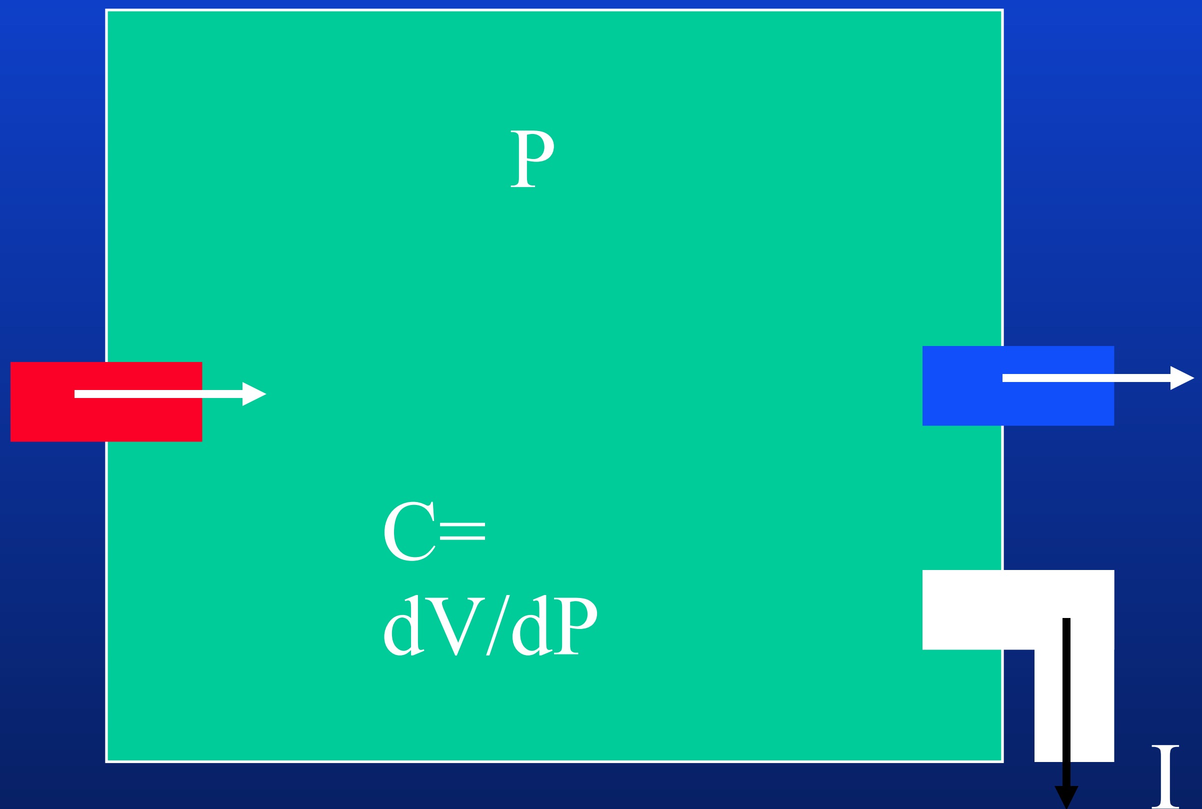
Outline

- Where have we been ?
- What have we accomplished?
- What remains unknown ?
- Where to we go from here ?

Intracranial Pressure



Compartment Models



$dV/dt = I_f - I_a - I_s$

Compartment Models of the Brain

$$C(P)\frac{dP}{dt} + \frac{1}{R_d}(P - P_d) = I_f$$

P is pressure
C is compliance
R is resistance to absorption
I if CSF formation

Typically choose 4 parameters
Po – opening pressure
Rd – resistance to absorption
Pd- saggital sinus pressure
If – CSF formation rate

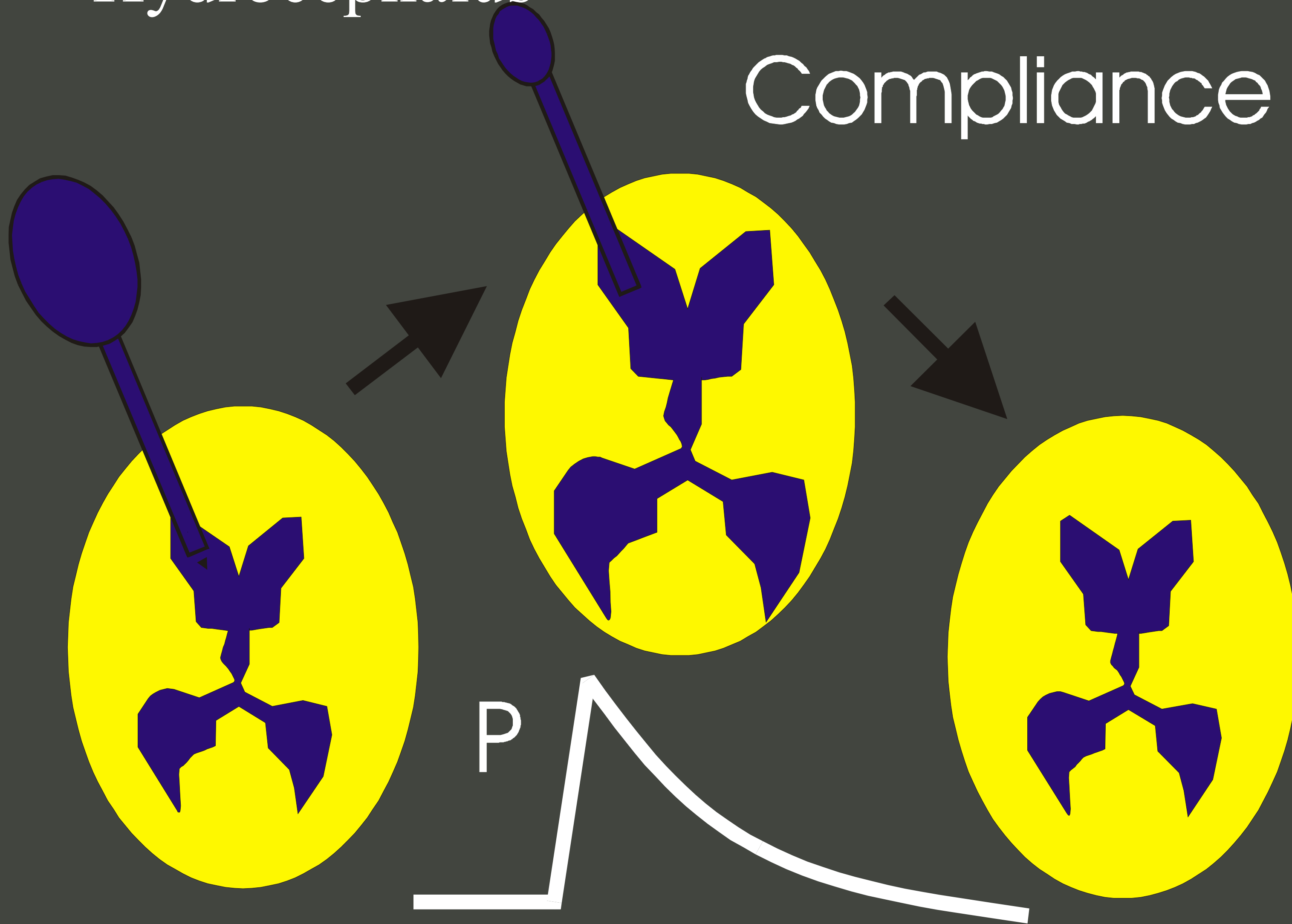
* Riccati Equation, 18th century

Compartment Models of the Brain

$$C(P)\frac{dP}{dt} + \frac{1}{R_d}(P - P_d) = I_f$$

Model	Reference
C(P) = Co	Guinane, 1972
=ae-bP	Lim, 1973
=1/kP	Marmarou, 1978 (pressure volume index)
= 1/(k1P +k2)	Sklar, 1977

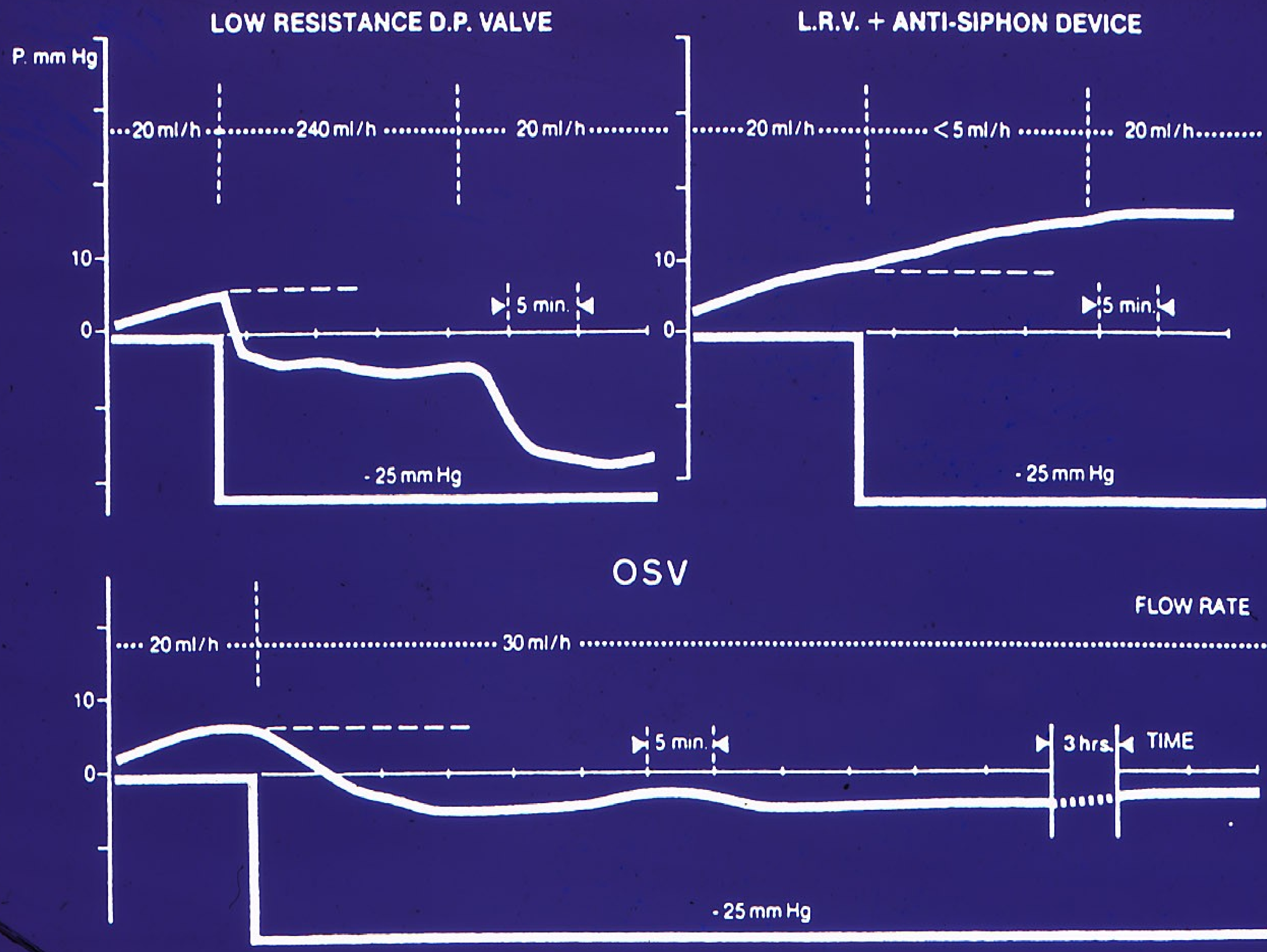
Mathematical Models of Hydrocephalus



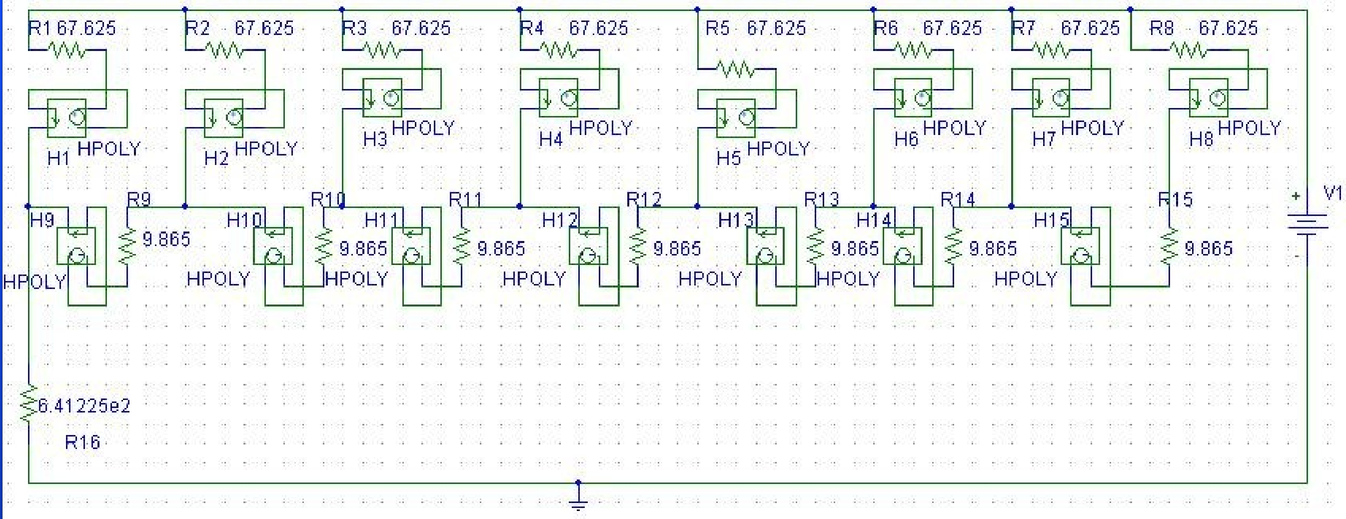
Compartment Models

- Explain
  - Transient response to bolus injection
  - CSF accumulation
  - CSF shunt performance
  - BUT
    - Have to fit 4 parameters
    - Infinite number of models

Drake (1998)



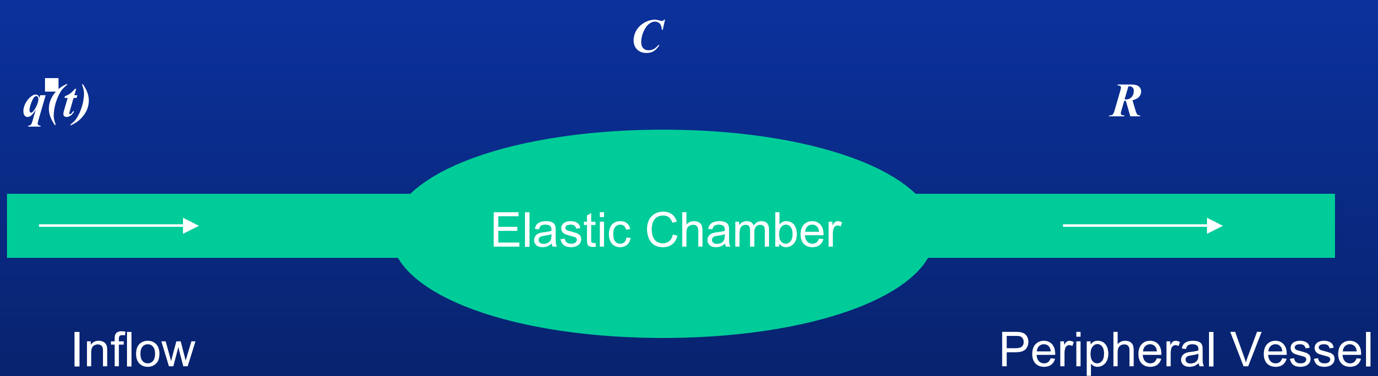
LOW RESISTANCE D.P. VALVE
L.R.V. + ANTI-SIPHON DEVICE
P. mm Hg
20 ml/h
240 ml/h
20 ml/h
20 ml/h
< 5 ml/h
20 ml/h
10
0
5 min.
5 min.
- 25 mm Hg
- 25 mm Hg
OSV
FLOW RATE
20 ml/h
30 ml/h
10
0
5 min.
3 hrs.
TIME
- 25 mm Hg


R1 67.625
R2 67.625
R3 67.625
R4 67.625
R5 67.625
R6 67.625
R7 67.625
R8 67.625
H1 HPOLY
H2 HPOLY
H3 HPOLY
H4 HPOLY
H5 HPOLY
H6 HPOLY
H7 HPOLY
H8 HPOLY
R9
R10
R11
R12
R13
R14
R15
H9
H10
H11
H12
H13
H14
H15
9.865
9.865
9.865
9.865
9.865
9.865
9.865
HPOLY
HPOLY
HPOLY
HPOLY
HPOLY
HPOLY
HPOLY
V1
6.41225e2
R16

Windkessel

Otto Frank (1899)

$$C\frac{dp}{dt} + \frac{1}{R}p = \dot{q}(t),$$



e.g.

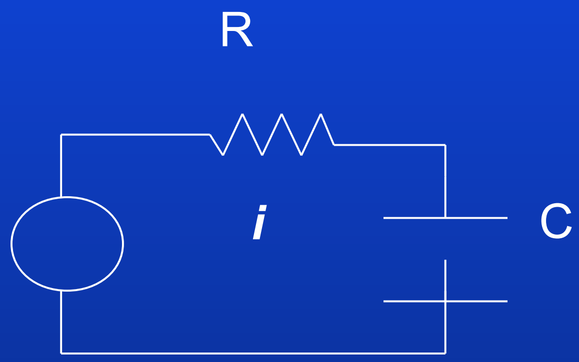
Pulsatility vs Convection

$If = I0$ CSf formation constant  Many authors

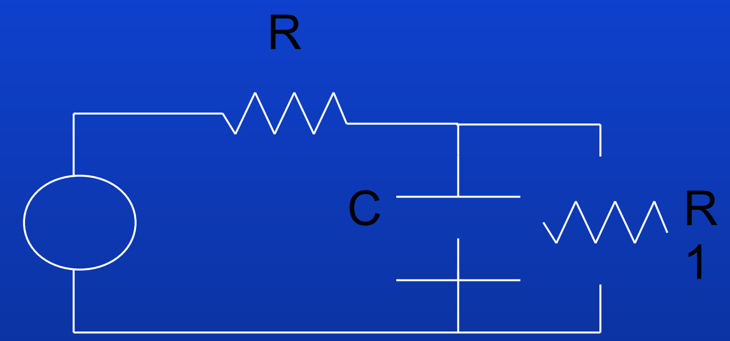
$If = H0$ Bolus injection  Marmarou

$If = q0 \sin 2 \varpi t$ Egnor

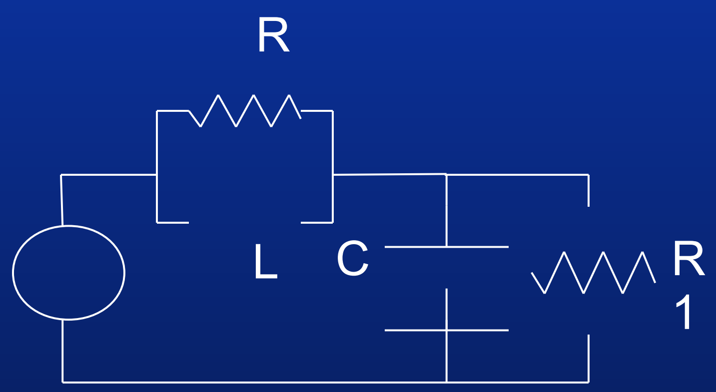
Windkessel
Electrical Analogs



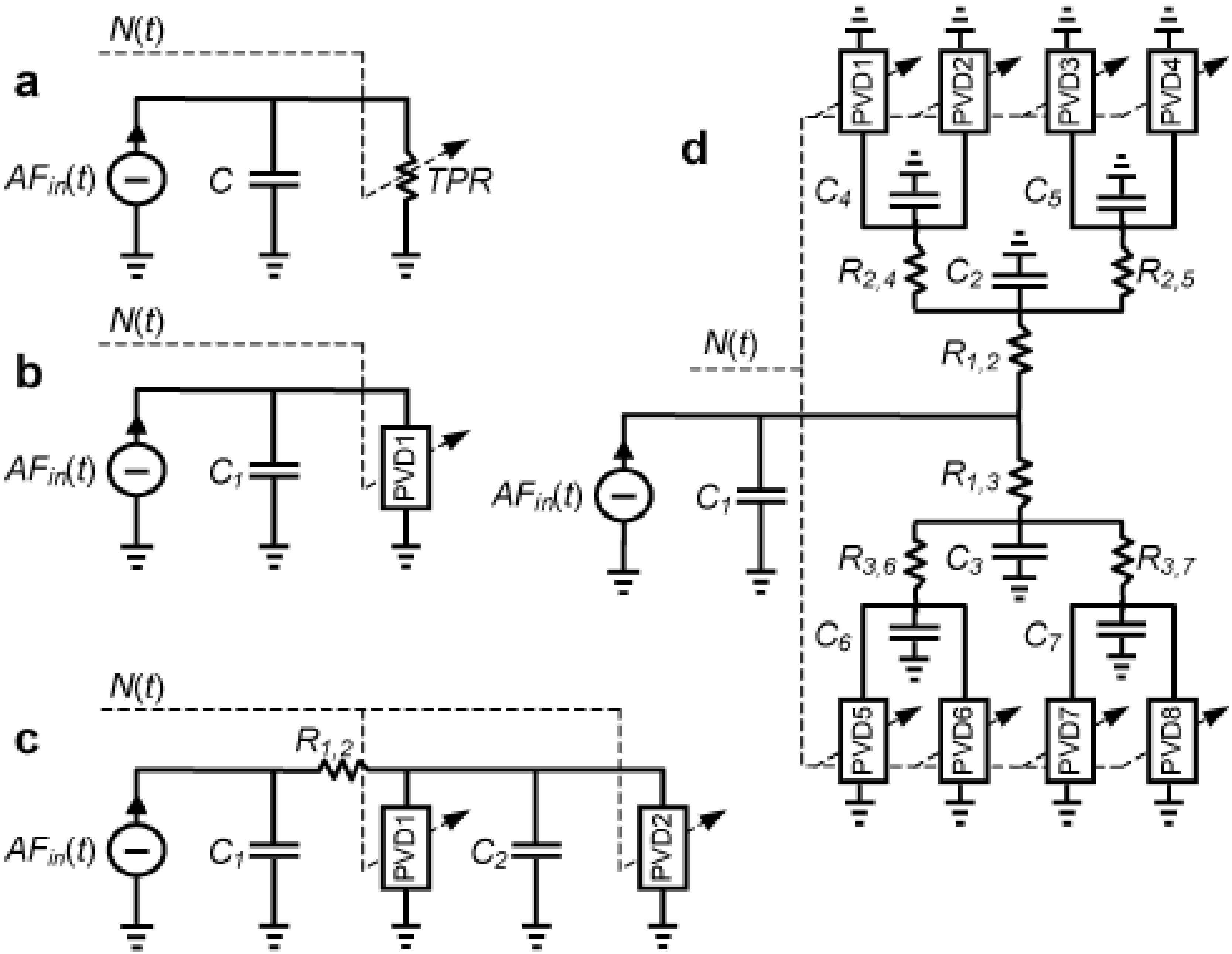
Two element



Three element



Four element


a
N(t)
AFin(t)
C
TPR
b
N(t)
AFin(t)
C1
PVD1
c
N(t)
R1,2
AFin(t)
C1
PVD1
C2
PVD2
d
PVD1
PVD2
PVD3
PVD4
C4
C5
R2,4
C2
R2,5
N(t)
R1,2
AFin(t)
C1
R1,3
R3,6
C3
R3,7
C6
C7
PVD5
PVD6
PVD7
PVD8

Pulsation Model

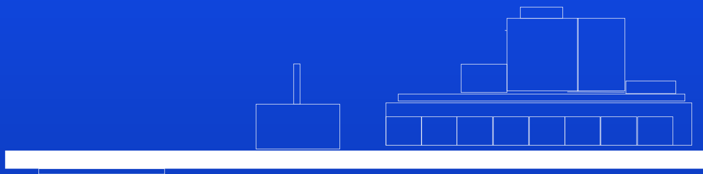
testing by approximation/orders of magnitude

- Windkessel and Resonance ?
- Biomechanical properties of brain must be a function of heart rate to maintain resonance
- Changes in flow velocity as a function of heart rate several orders of magnitude greater than MRI data
- Forces on CSF smaller by several orders of magnitude than anticipated
- Pulsation might be quite important, but none of models have elucidated any mechanism

Problems common to all Compartment Models

- Brain is basically a balloon
- Parameters fit to anticipated result
- Little insight to pathologic process
- No “spatial” information on pressure, stress, strain, or “pulsation”

Nulsen and Spitz - Original Ball Valve



Medos Valve

Diaphragm valve

Delta Valve

Anti-siphon device

Orbis Sigma

Horizontal Vertical Valve

750 Hydrocephalus Valves Tested in Vitro
and a Review on 691 Tests Reported in Literature

Aschoff A, Benesch C, Biedermann D, El Tajeh, Fruh K, Hashemi B, Klank A, Ludwig J, Oikonomou J,

Conclusions

1. There are at least **1448** independently tested valves; unfortunately many studies seem to be unknown to most neurosurgeons and even the **authors of ”Shunt-Books**”.

The quality of methods and reliability ranges between class I - III. An increasing number of tests meets class I, in the last decade > 50%.

There is no major review, metaanalysis, Cochrane-study or data-bank of results. However, the publications of the U.K. Shunt Evaluation Group and own papers may be first steps (Aschoff 95).

2. Official tests (ASTM, ISO, shunt companies) are too short, ignore common potentially disturbing factors and include failures in test methodology (ASTM = class III, ISO = class II).

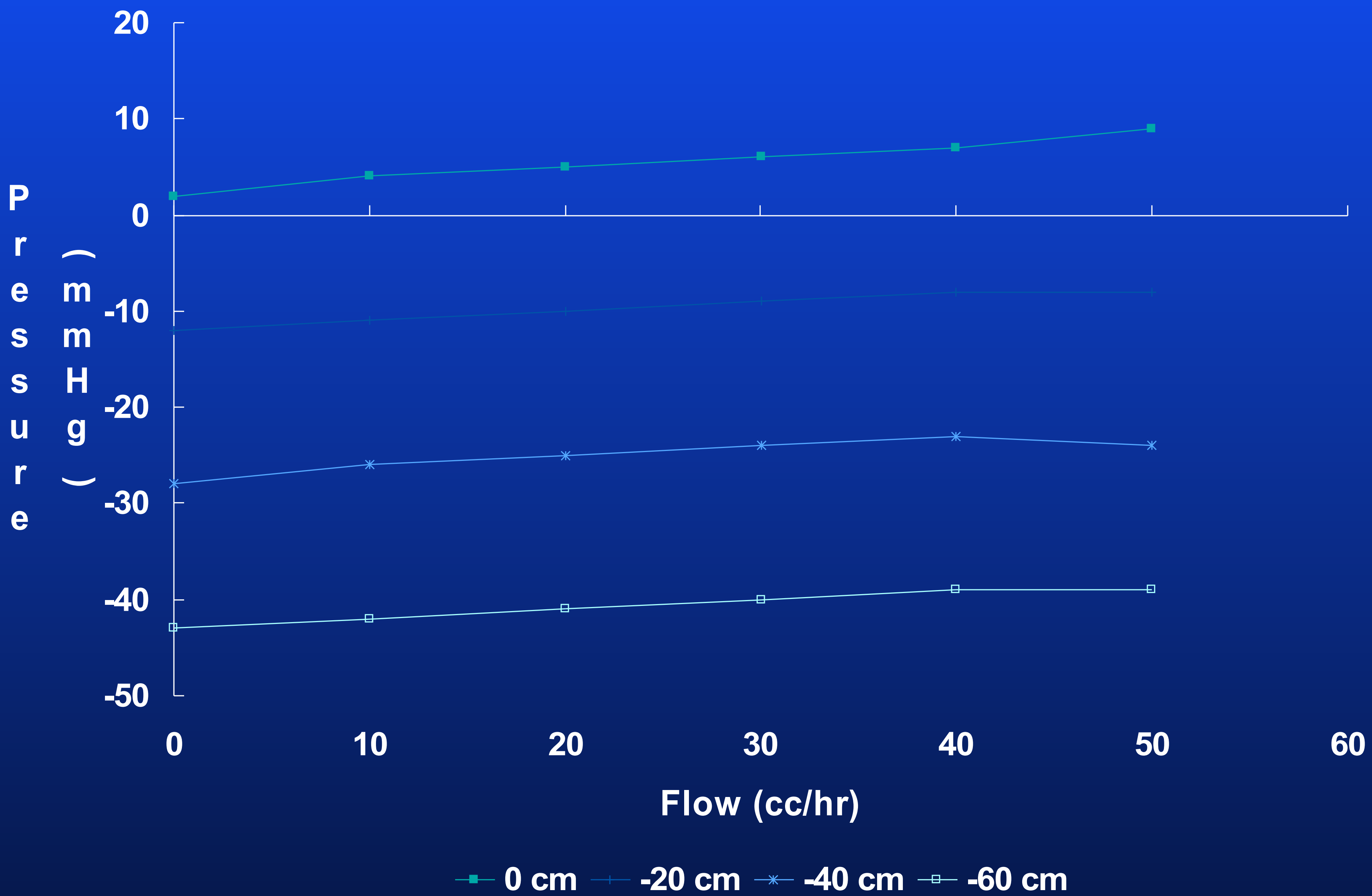
3. Of 148 valves on the world market **10** are well-investigated (statistically sufficient sample size, class I-, long-term-, safety tests). Approx. 40% have **never** been tested independently, in 50% we have only anecdotal data.

4. Many valves showed deficits in accuracy, long-term-stability, and safety, the vast majority presented adequate flow-rates in either the upright or horizontal positions only, not in both.

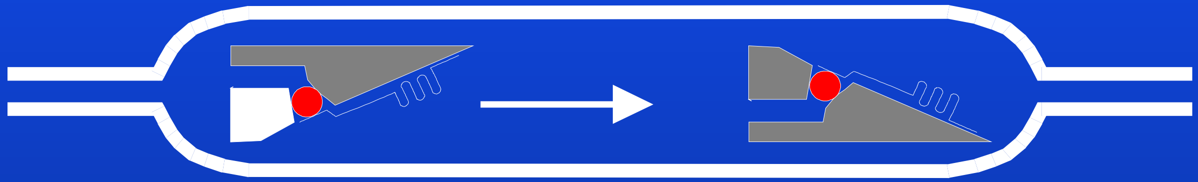
5. The evident clinical success in approx. 80% of cases, despite poor shunt technology, may be attributed to the enormous adaptability of the patients and not to valves.

6. "Smart" shunts are not a ”Mission Impossible”, but up to now ignored by most neurosurgeons and even shunt experts.

CSF Shunt Tubing

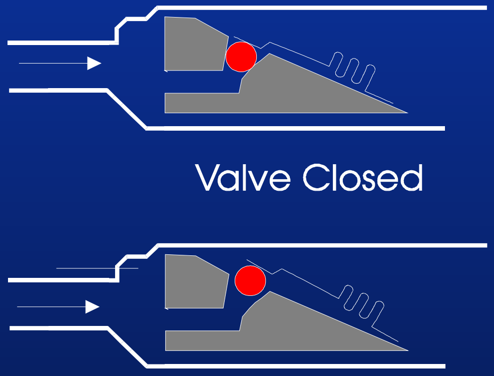


Standard Differential Pressure Valve



Mechanism

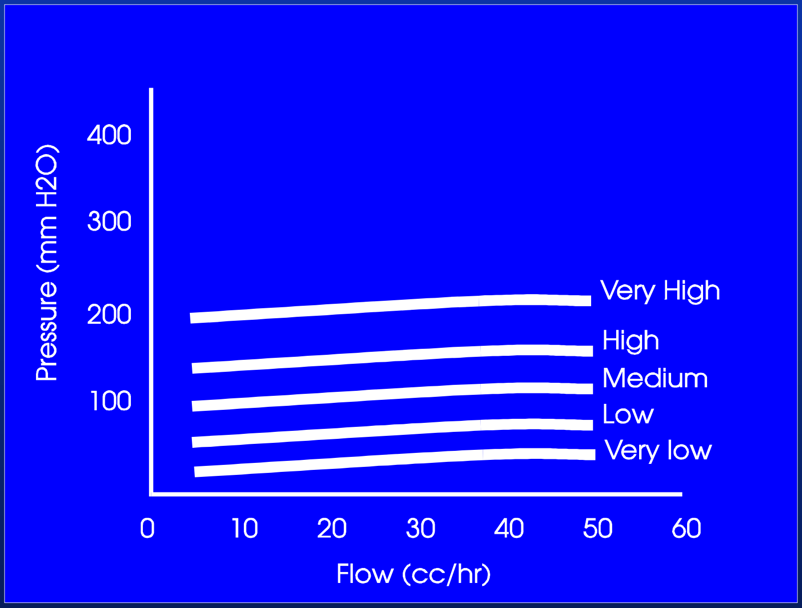
Spring-Ball Valve



Valve Closed

Valve Open

Pressure Flow Characteristics



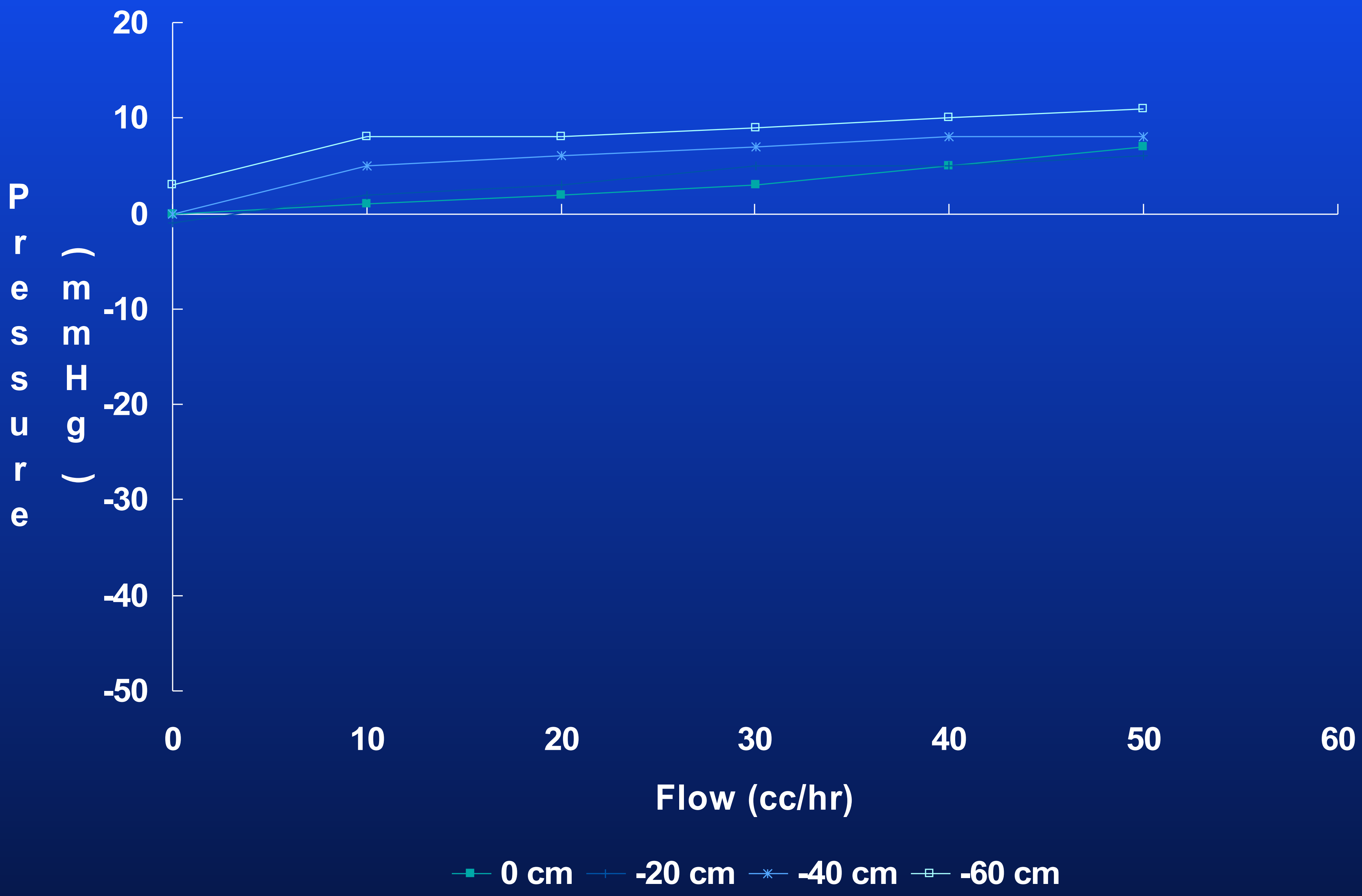
mobile
diaphragm

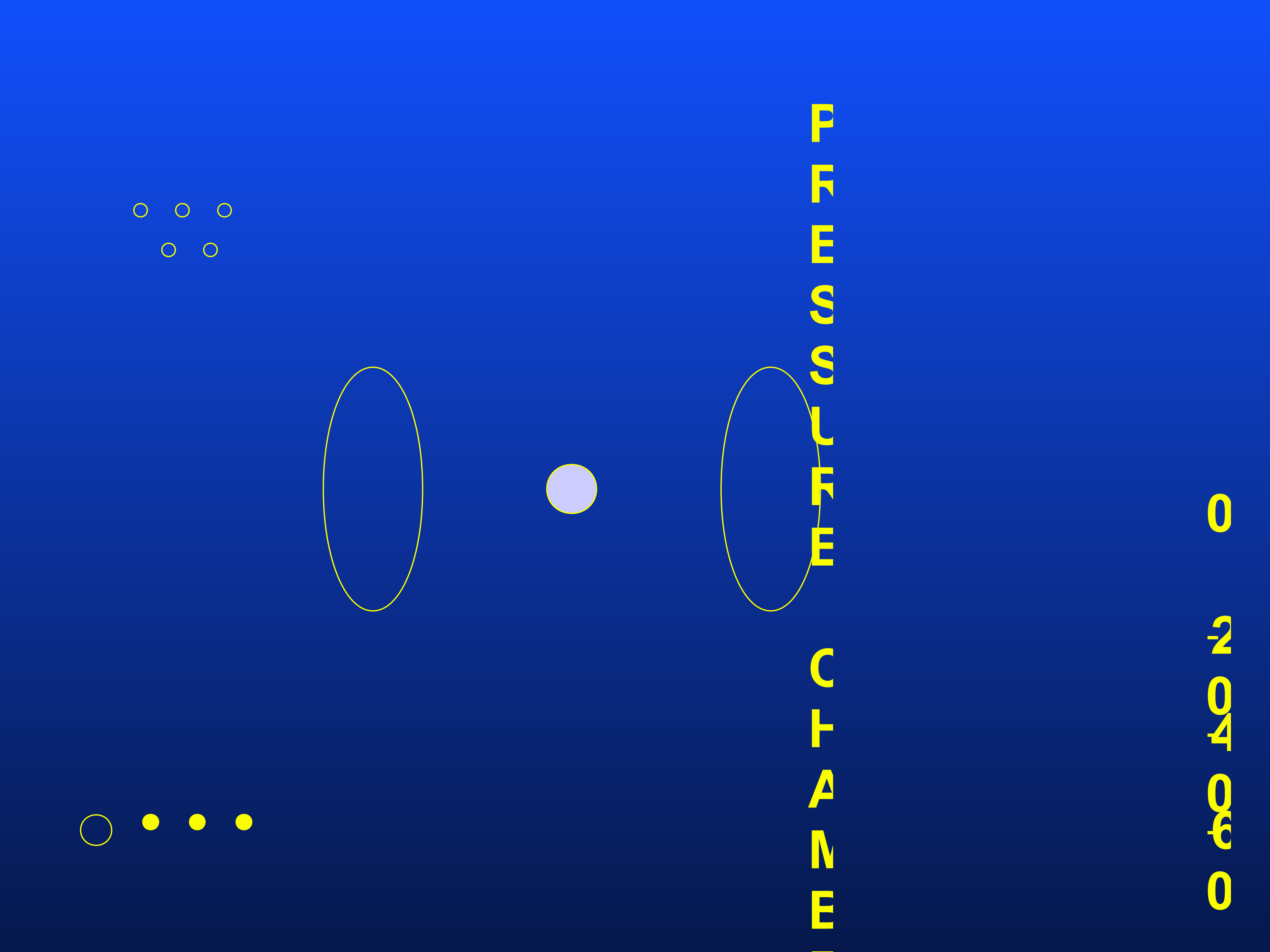
LOW
RESISTANCE
External Pressure -
Atmospheric
Internal Pressure - Positive

HIGH RESISTANCE
External Pressure - Atmospheric
Internal Pressure - Negative
(siphoning)

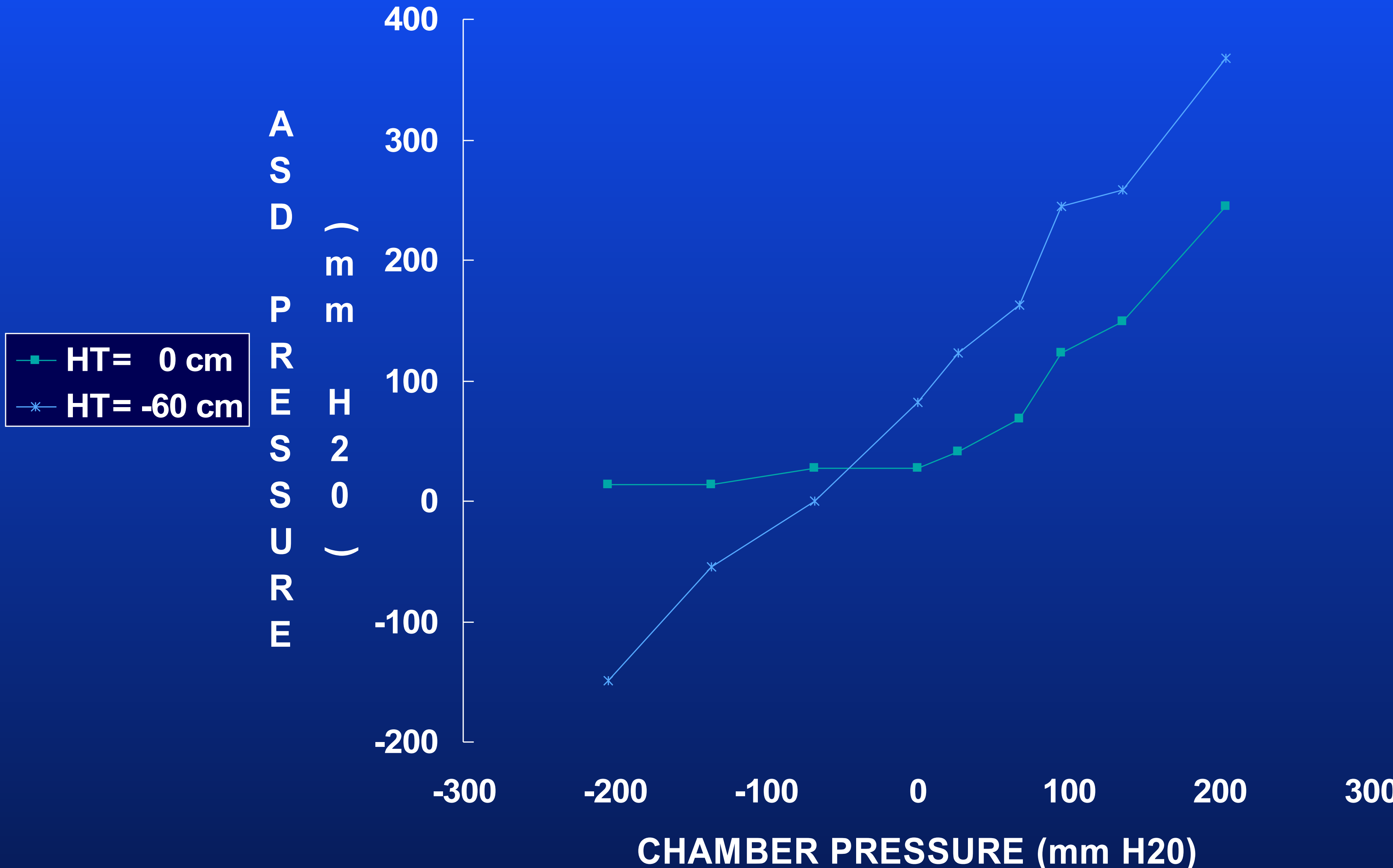
HIGH RESISTANCE
External Pressure - Positive (Tissue
Capsule)

PS Medical ASD




PRESSURE
CHAMBER
0
-20
-40
-60

ASD PRESSURE vs CHAMBER



(Flow Rate = 10

o
s &
c
i
l
l
o
s
c
o
p
e
i

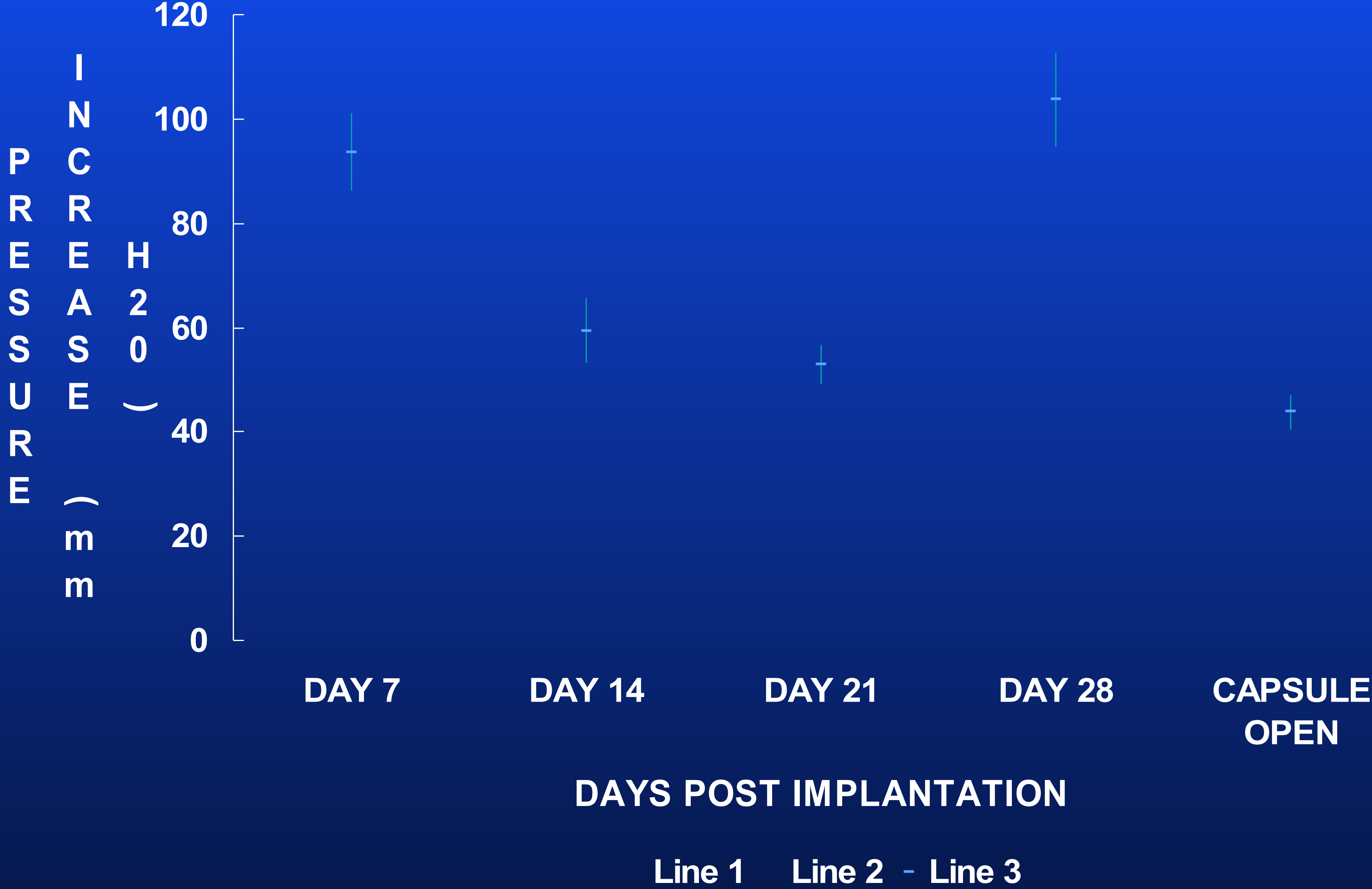
p
r
e
s
s
u
r
e

t
r

C
-2
0
-4
0
-6

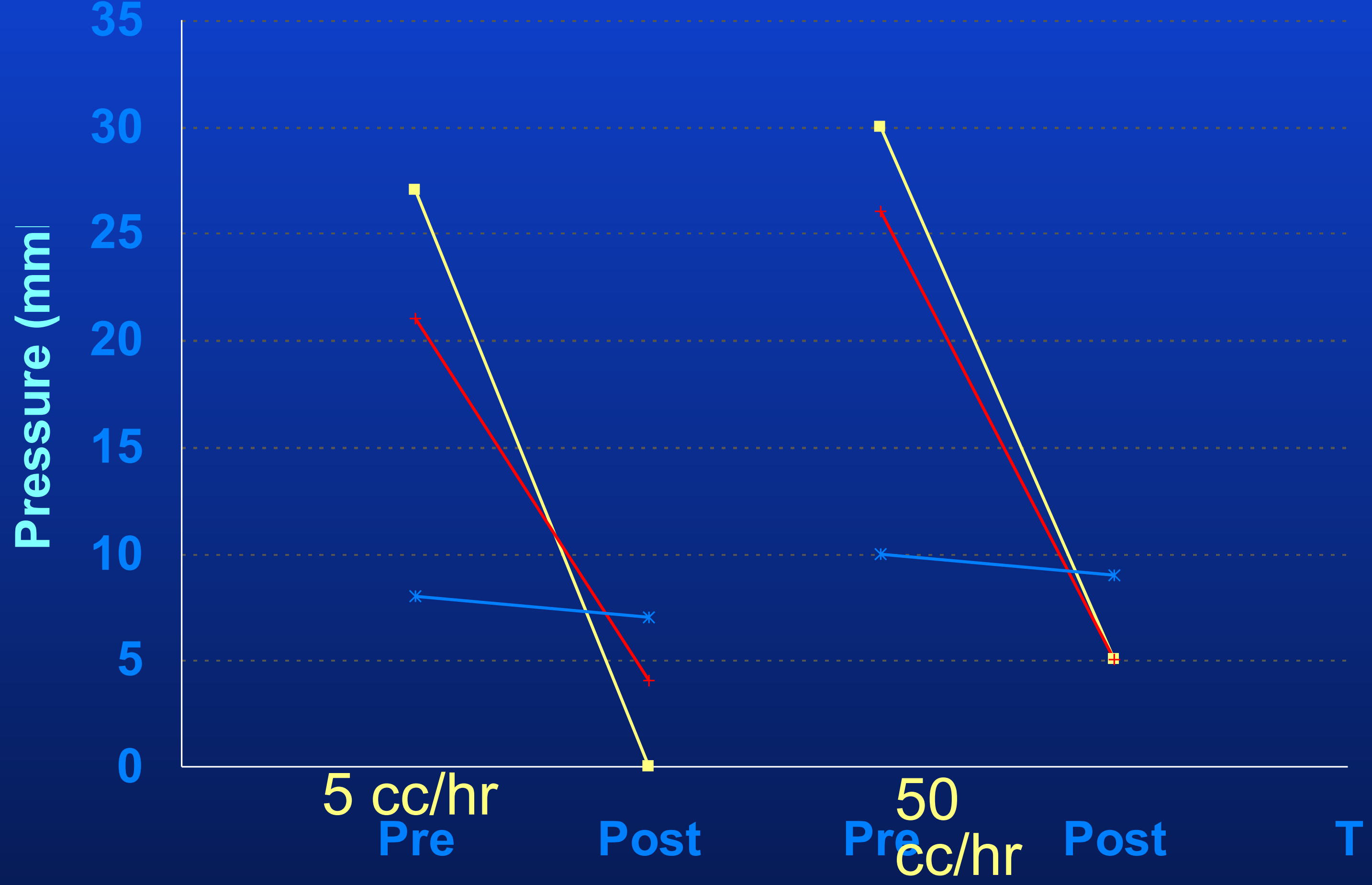
c
n
c
n
c
n
c

Average Change Infusion Pressure Post ASD Implantation



Anti-siphon Device Pressure

Pre and Post Capsule Release



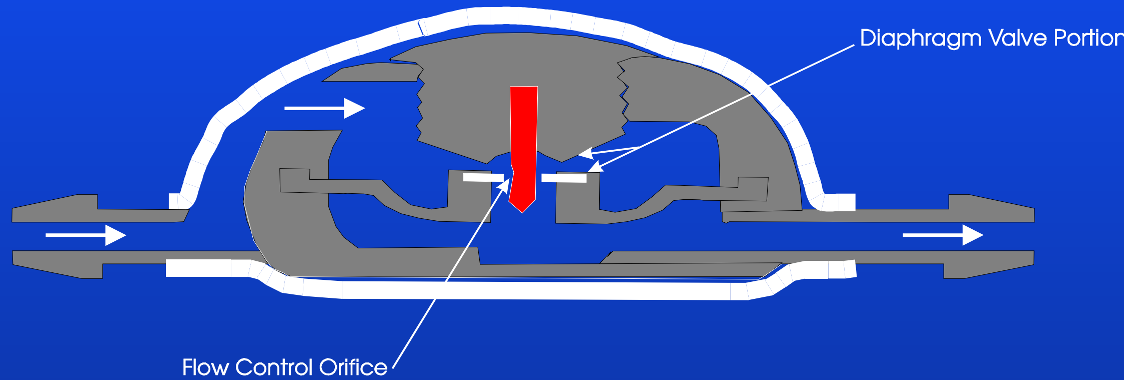
J Neurosurg 78:568–573, 1993

Tonsillar herniation: the rule rather than the exception after lumboperitoneal shunting in the pediatric population

PAUL D. CHUMAS, M.B., F.R.C.S.(ED), DEREK C. ARMSTRONG, M.D., F.R.C.P.(C), JAMES M. DRAKE, M.B.,B.CH., F.R.C.S.(C), ABHAYA V. KULKARNI, HAROLD J. HOFFMAN, M.D., F.R.C.S.(C), ROBIN P. HUMPHREYS, M.D., F.R.C.S.(C), JAMES T. RUTKA, M.D., F.R.C.S.(C), AND E. BRUCE HENDRICK, M.D., F.R.C.S.(C)

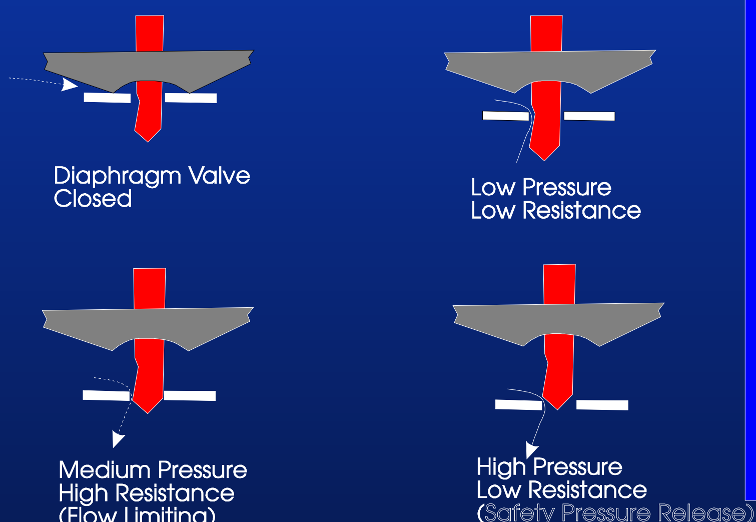
Divisions of Neurosurgery and Neuroradiology, The Hospital for Sick Children, University of Toronto, Toronto, Ontario, Canada

Cordis Orbis Sigma

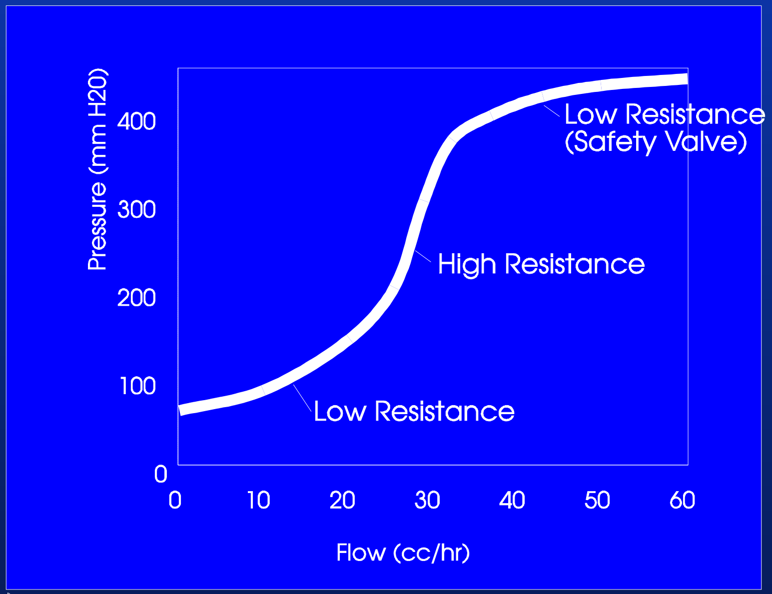


Mechanism

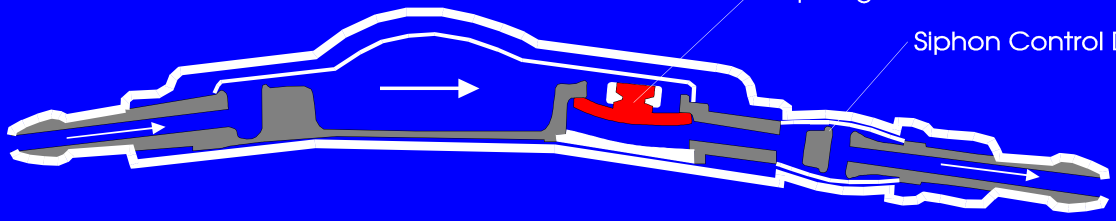
Variable Resistance Valve



Pressure Flow Characteristics

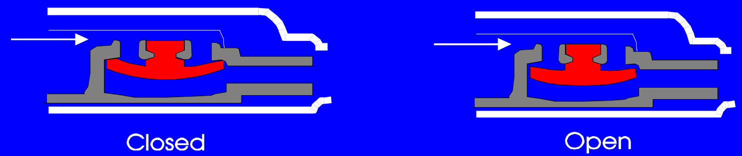


PS Medical Delta Valve



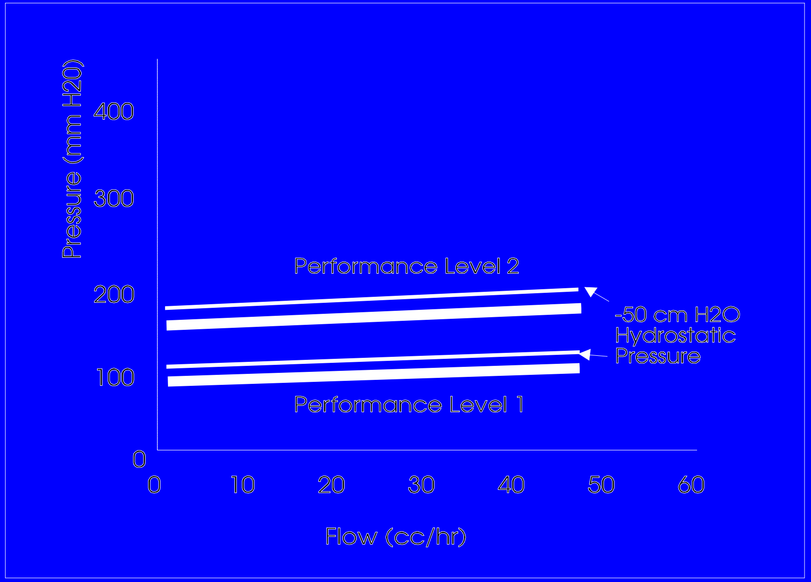
Mechanism

Diaphragm Valve

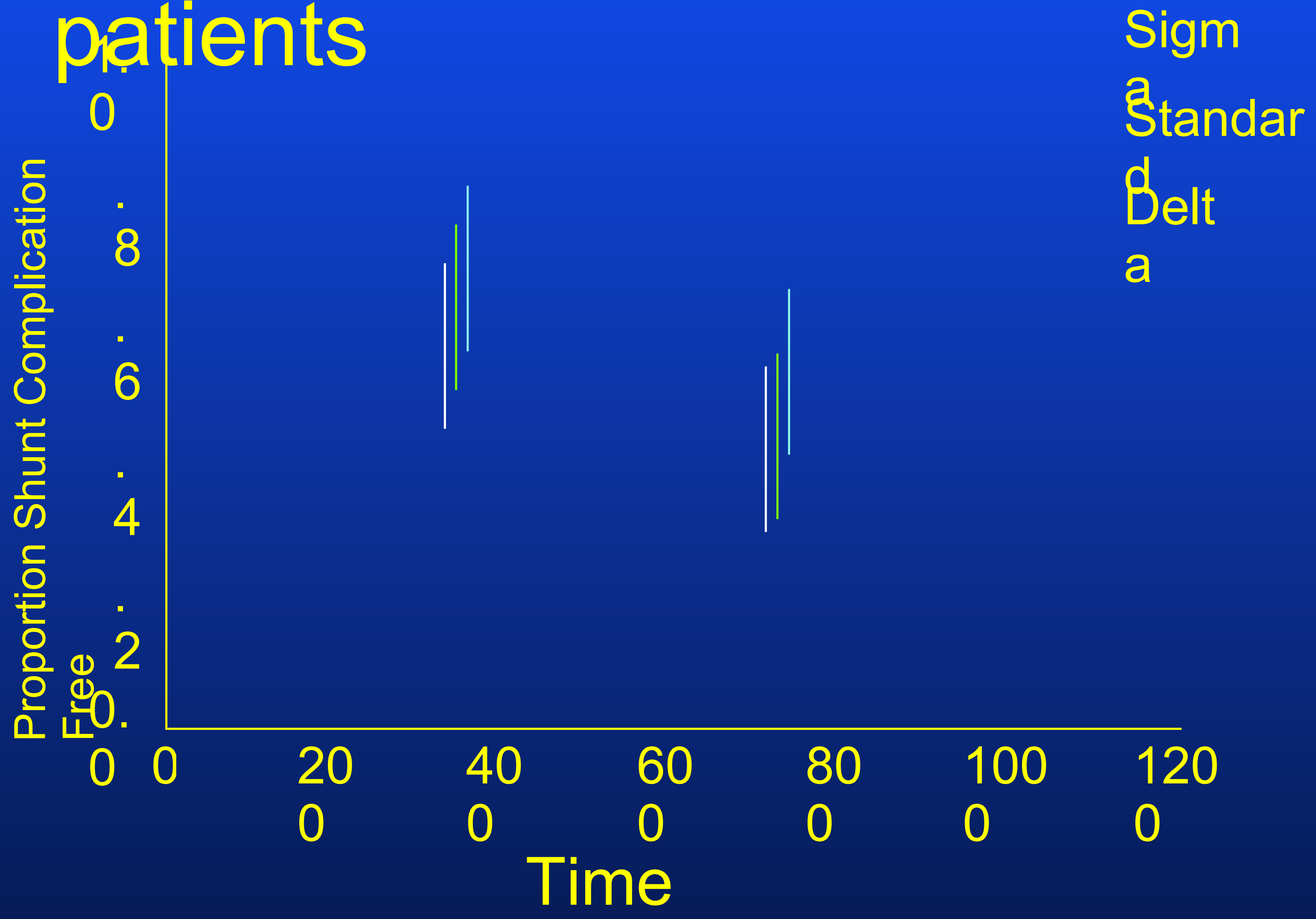


Siphon Control Device (SCD)

Pressure Flow Characteristics

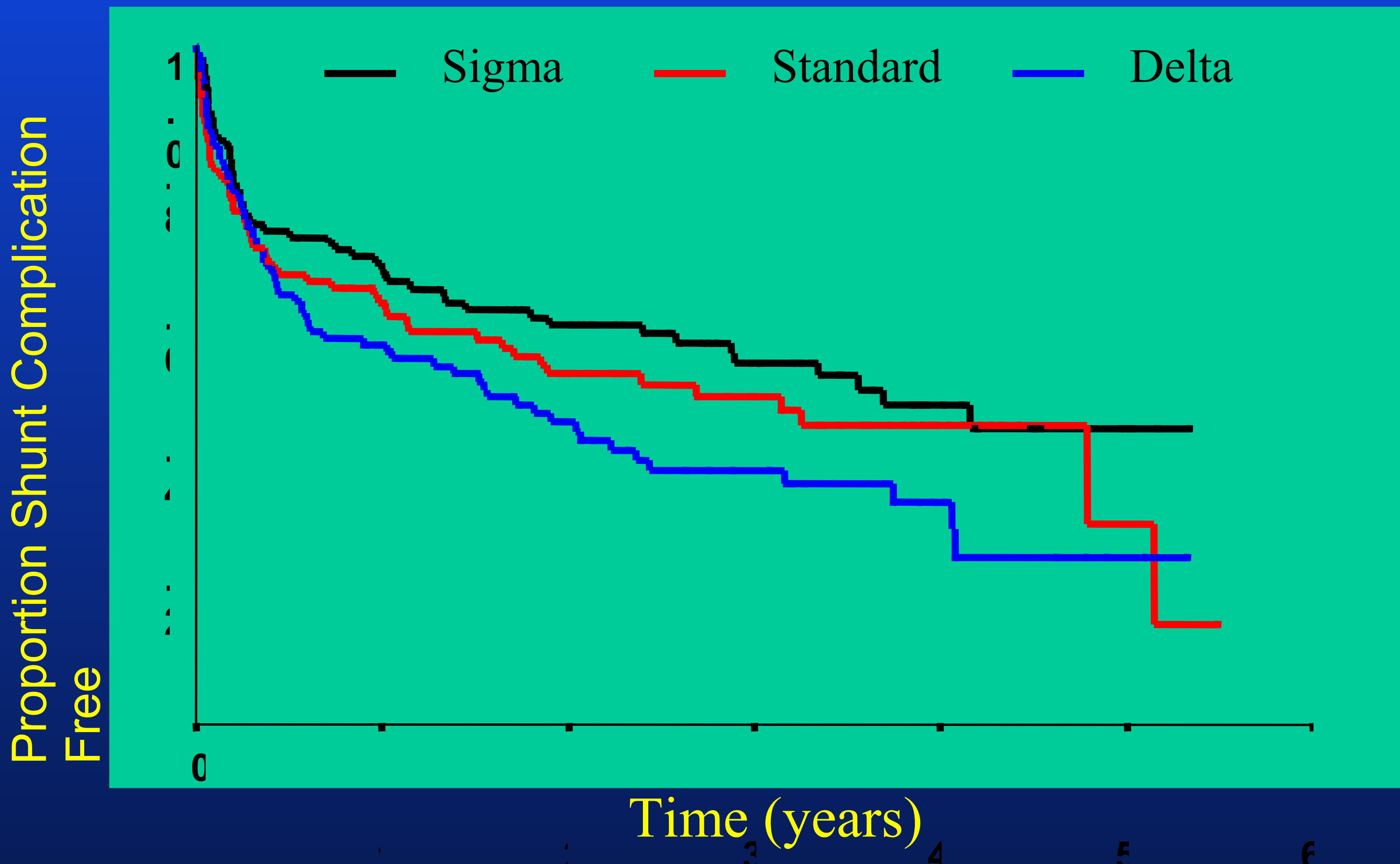


Shunt Design Trial - 344 patients



Drake, J.M., Kestle J.R.W., Milner R. et al. Neurosurgery 43:294-305, 1998

Shunt Design Trial - Long term follow up



Kestle J.R.W., Drake J.M. et al, Pediatr Neurosurg 33:230-236, 2000

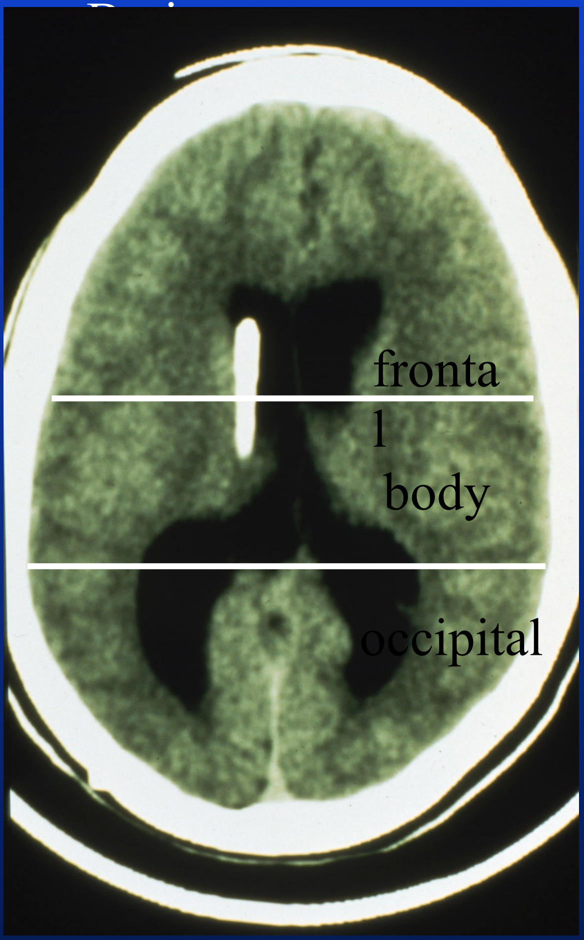
Secondary outcomes: location of obstruction

	Delta (38)	Standard (39)	Sigma (31)
Ventricular catheter	16	18	2
Valve	2	5	8
Distal	2	1	5
Peritoneal catheter	5	2	2
Migration, Disconnection, Fracture	3	7	7
Unknown	10	6	7

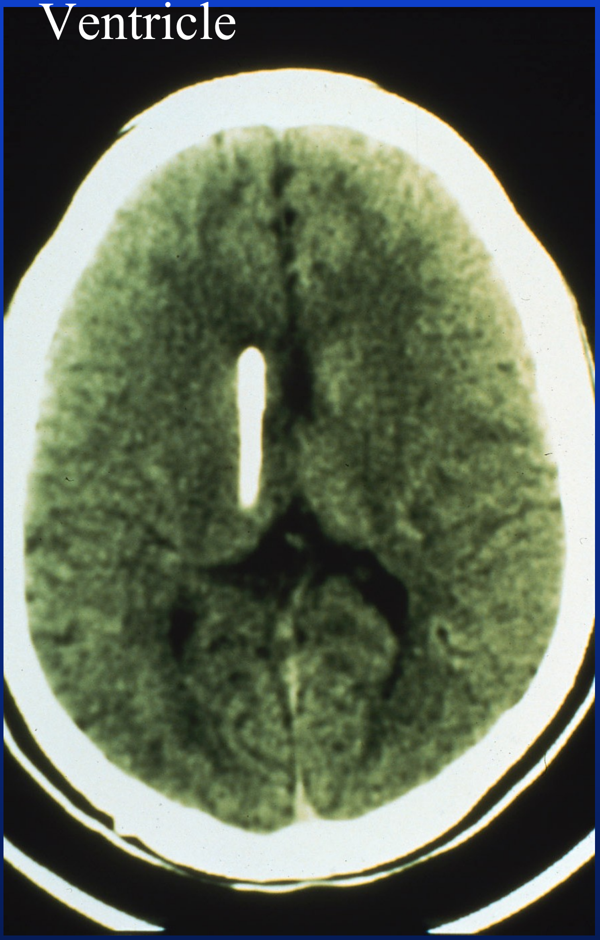
Imaging Analysis Shunt Design Trial

Surrounded by CSF

Touching

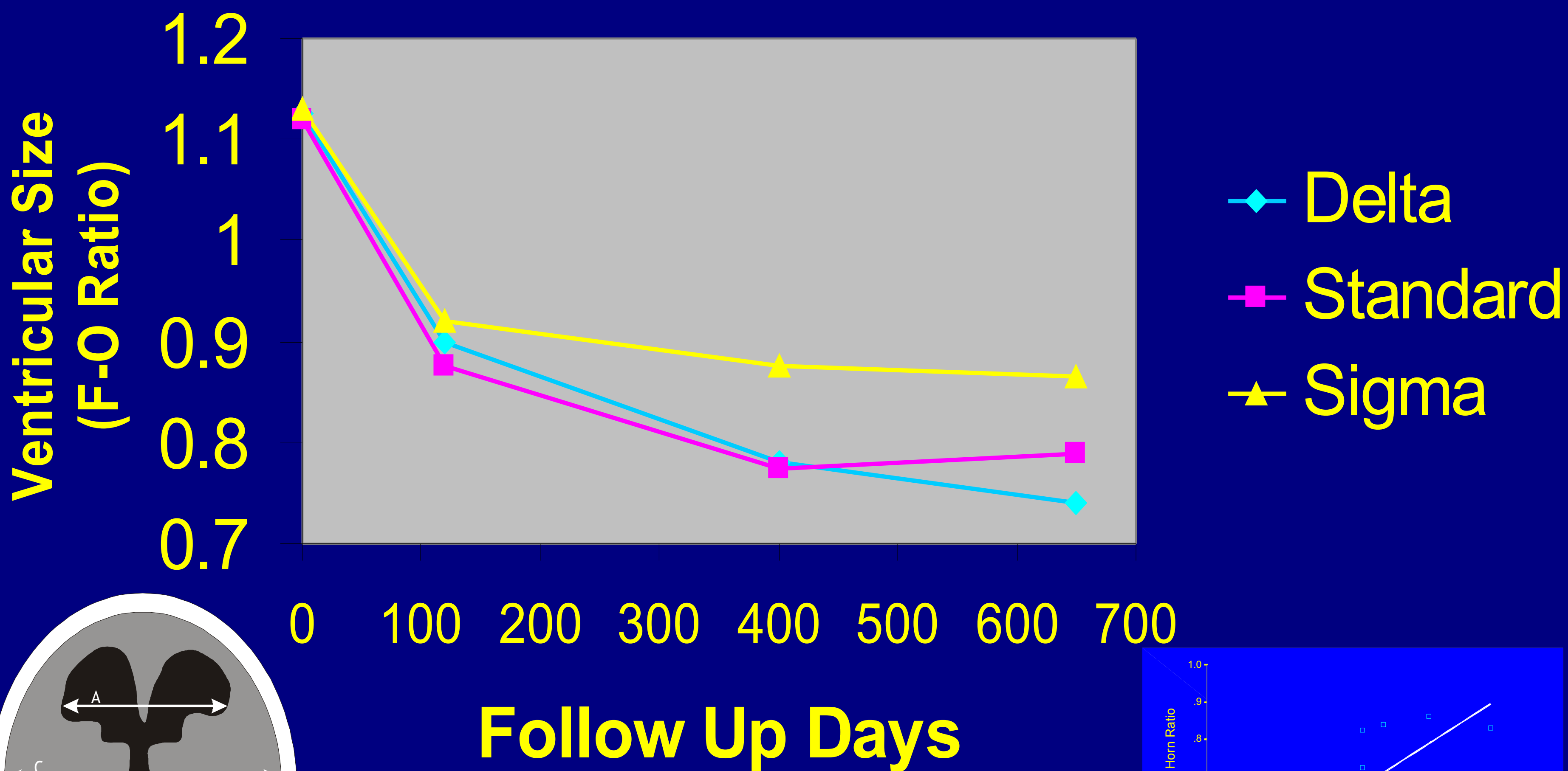


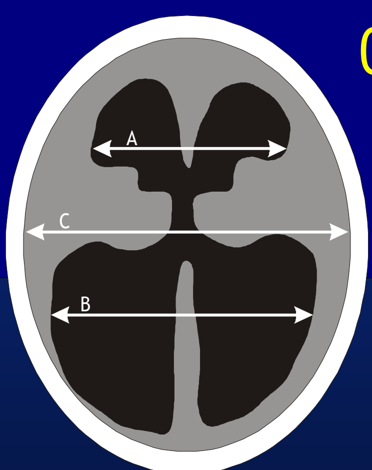
Surrounded by Ventricle



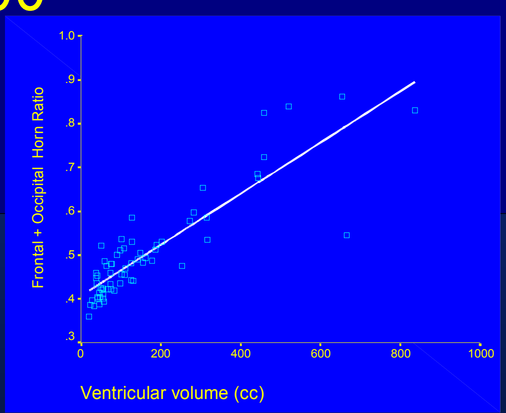
* Failure scans

Ventricular Size By Valve





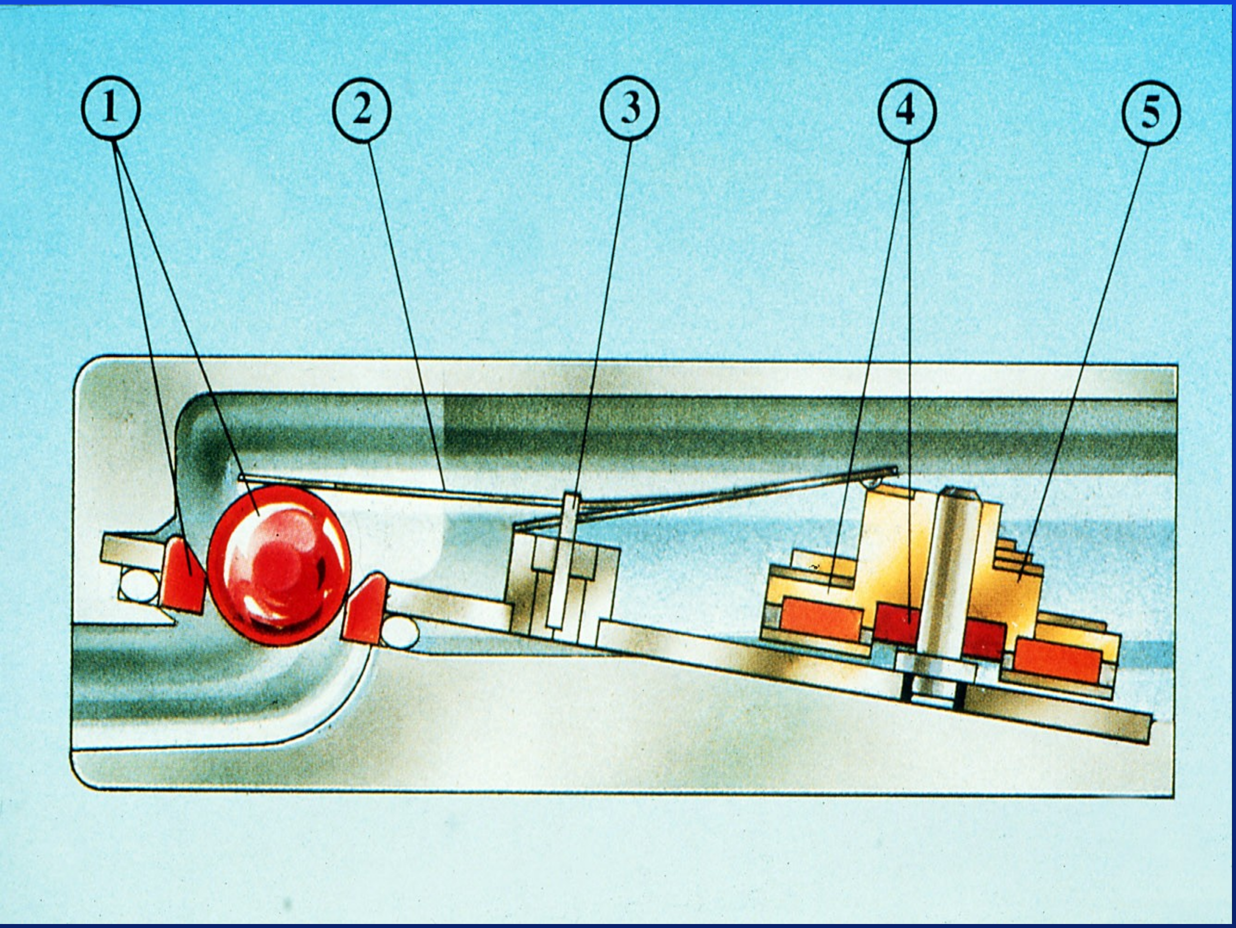
F-O Ratio = (A+B)/2C



Bench Testing $\simeq$ In Vivo Performance

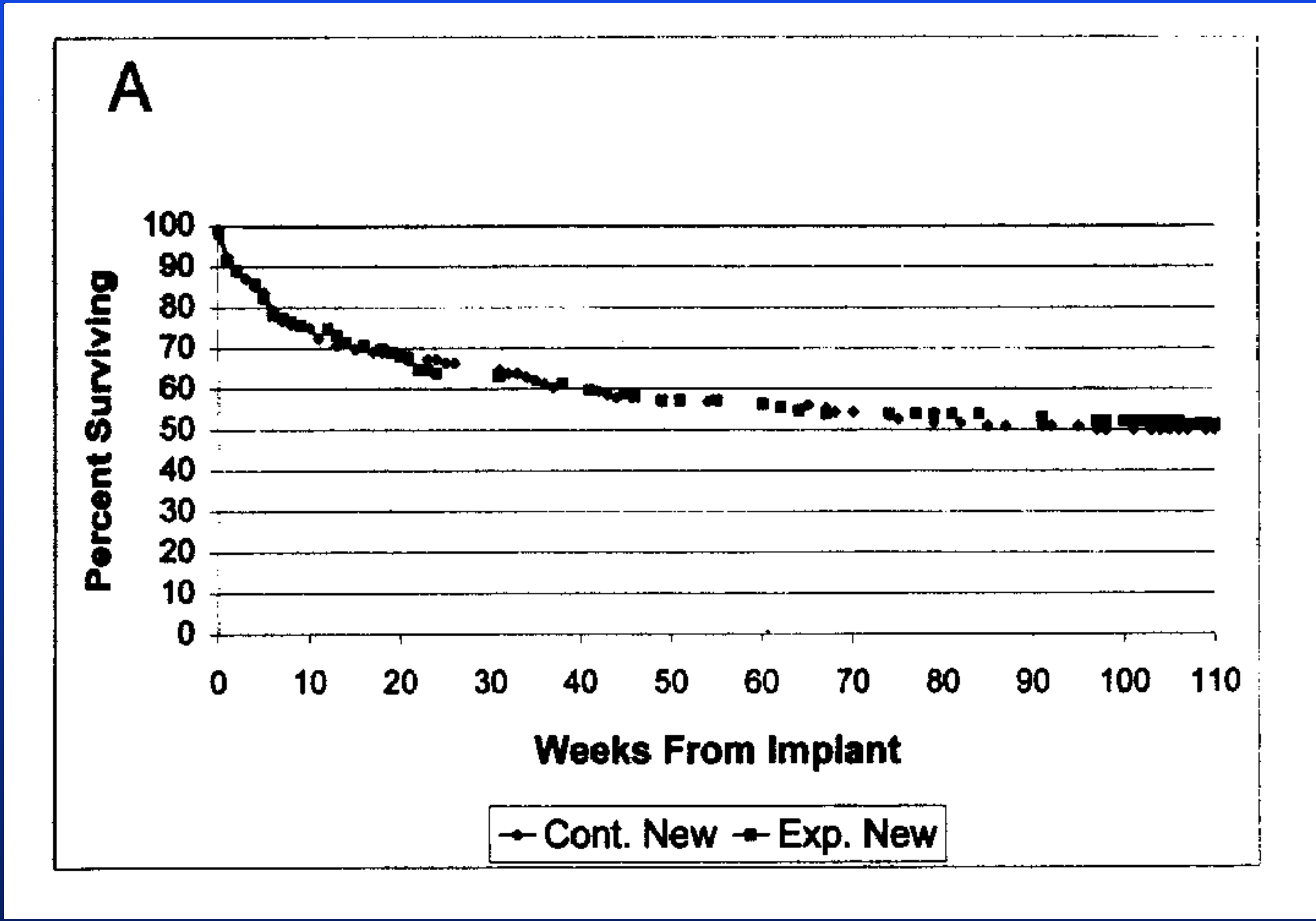
Bench Testing $\neq$ Clinical Outcome

Medos Adjustable (programmable) valve



Procedure for adjusting valve

Medos Trial - Prospective, randomized, 377 patients



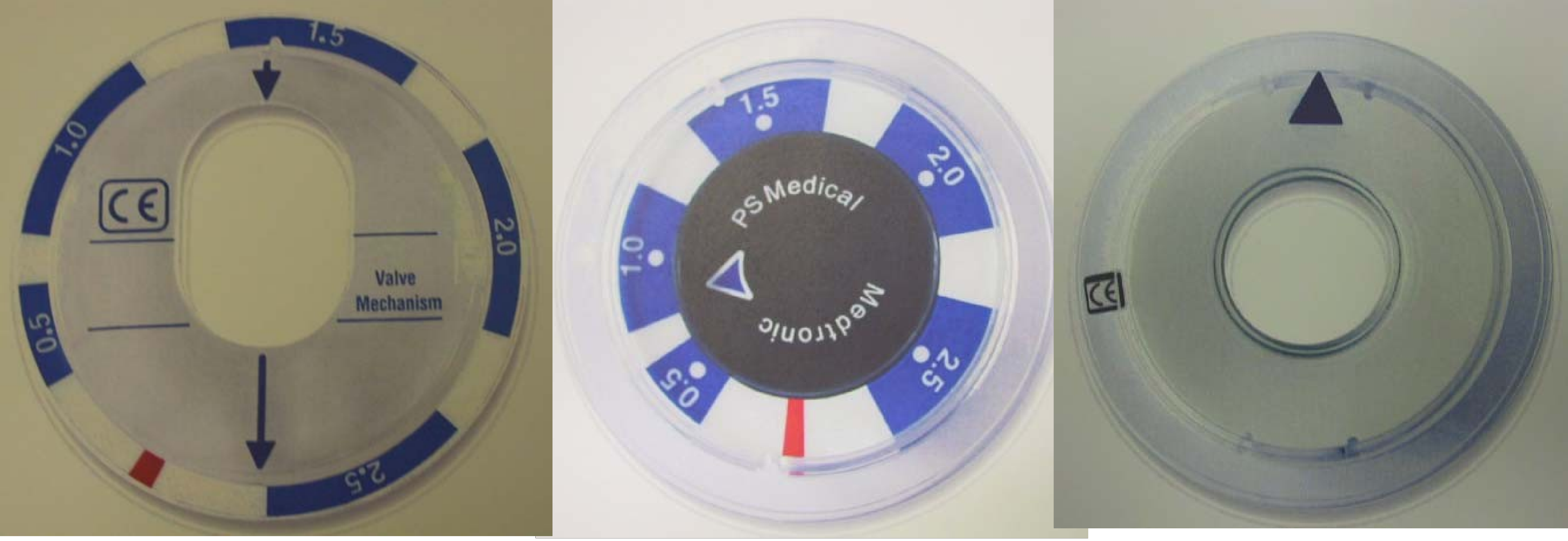
Pollack I., Albright L., Adelson D. et al, Neurosurgery 45:1399-1411, 1999

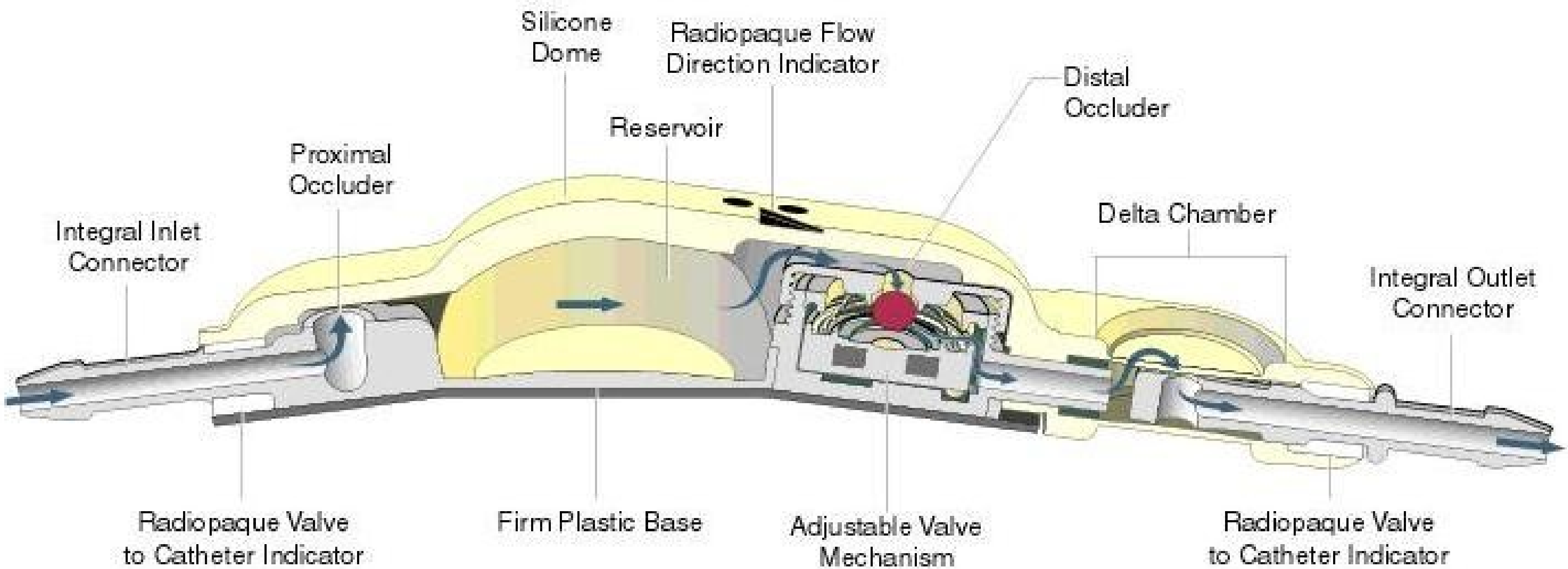
Alteration of the pressure setting of a Codman-Hakim programmable valve by a television.

Utsuki S, Shimizu S, Oka H, Suzuki S, Fujii K.

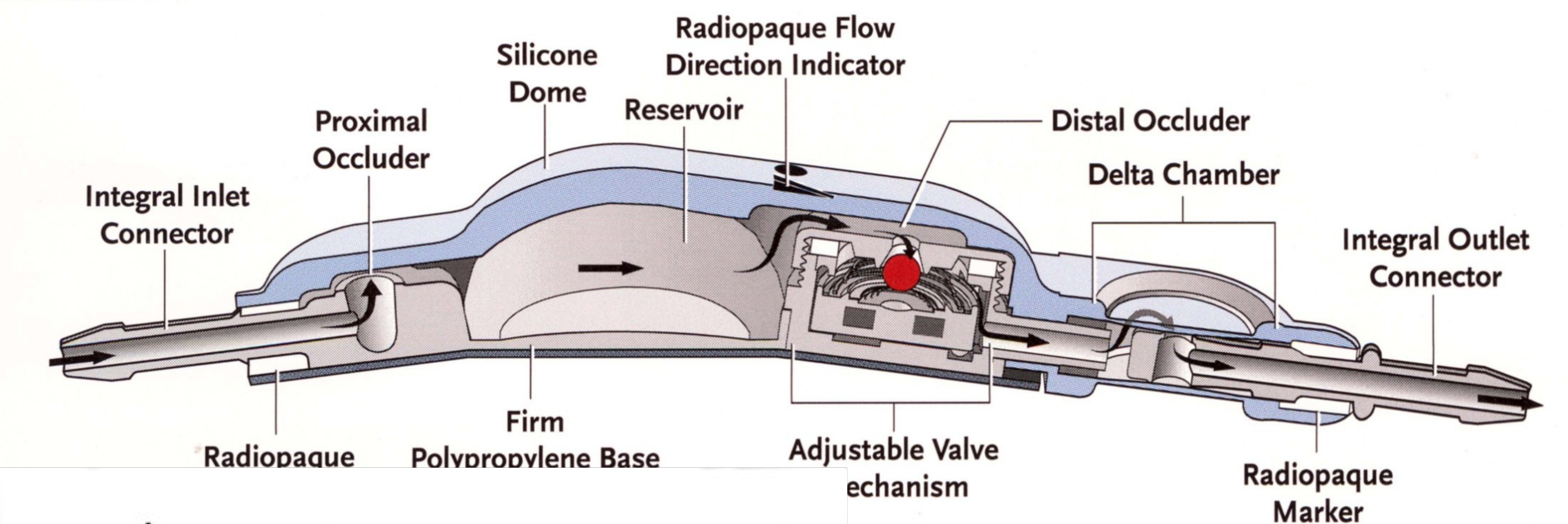
A 7-year-old girl presented in semicomatose condition. She had received a ventriculoperitoneal shunt using a Codman-Hakim programmable valve. Head computed tomography demonstrated hydrocephalus and head radiography showed that the pressure setting of the shunt valve had changed to 60 mmH(2)O from 40 mmH(2)O. The pressure setting was returned to 40 mmH(2)O, and she was discharged because her clinical symptoms and hydrocephalus improved. One month later, she lost consciousness again and was transported to our hospital. Hydrocephalus and shunt valve pressure of 50 mmH(2)O were noted, and the pressure setting was returned to 40 mmH(2)O again. She was discharged without complications. We suspected that the valve pressure was caused by close contact with a television, because the patient tended to touch a television with her head during play. The valve pressure did not change after the television was placed on a high stand out of reach. We should recognize that there are many sources of weak magnetic fields that may influence a programmable valve in everyday life.

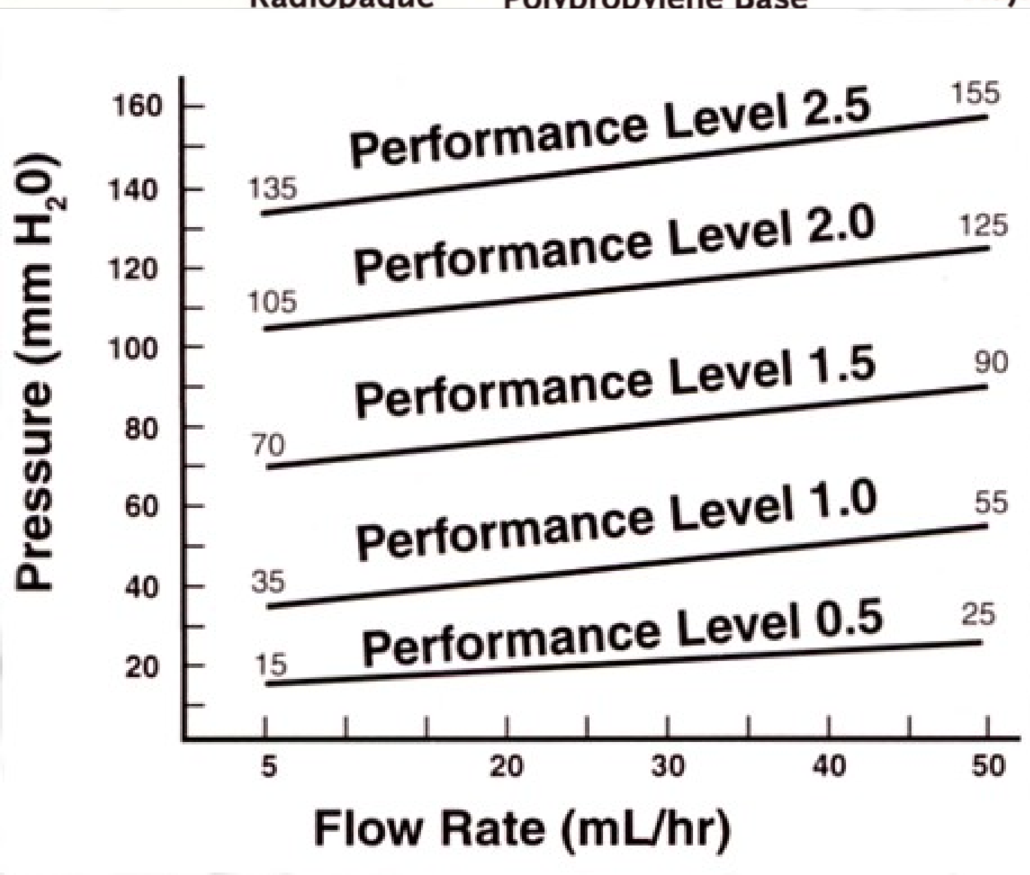
Neurol Med Chir (Tokyo). 2006 Aug;46(8):405-7



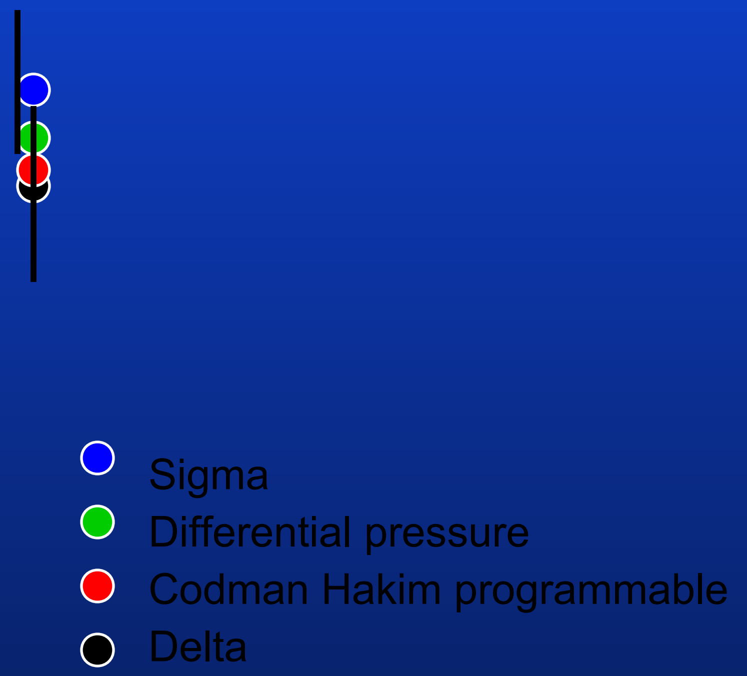


STRATA Adjustable Valve


Radiopaque Flow
Direction Indicator
Silicone
Dome
Reservoir
Proximal
Occluder
Distal Occluder
Delta Chamber
Integral Inlet
Connector
Integral Outlet
Connector
Radiopaque
Firm
Polypropylene Base
Adjustable Valve
Radiopaque
Marker


Pressure (mm $H_2$0)
160
140
120
100
80
60
40
20
Performance Level 2.5
135
155
Performance Level 2.0
105
125
Performance Level 1.5
70
90
Performance Level 1.0
35
55
Performance Level 0.5
15
25
5
20
30
40
50
Flow Rate (mL/hr)

Shunt survival – Core group Strata Valve

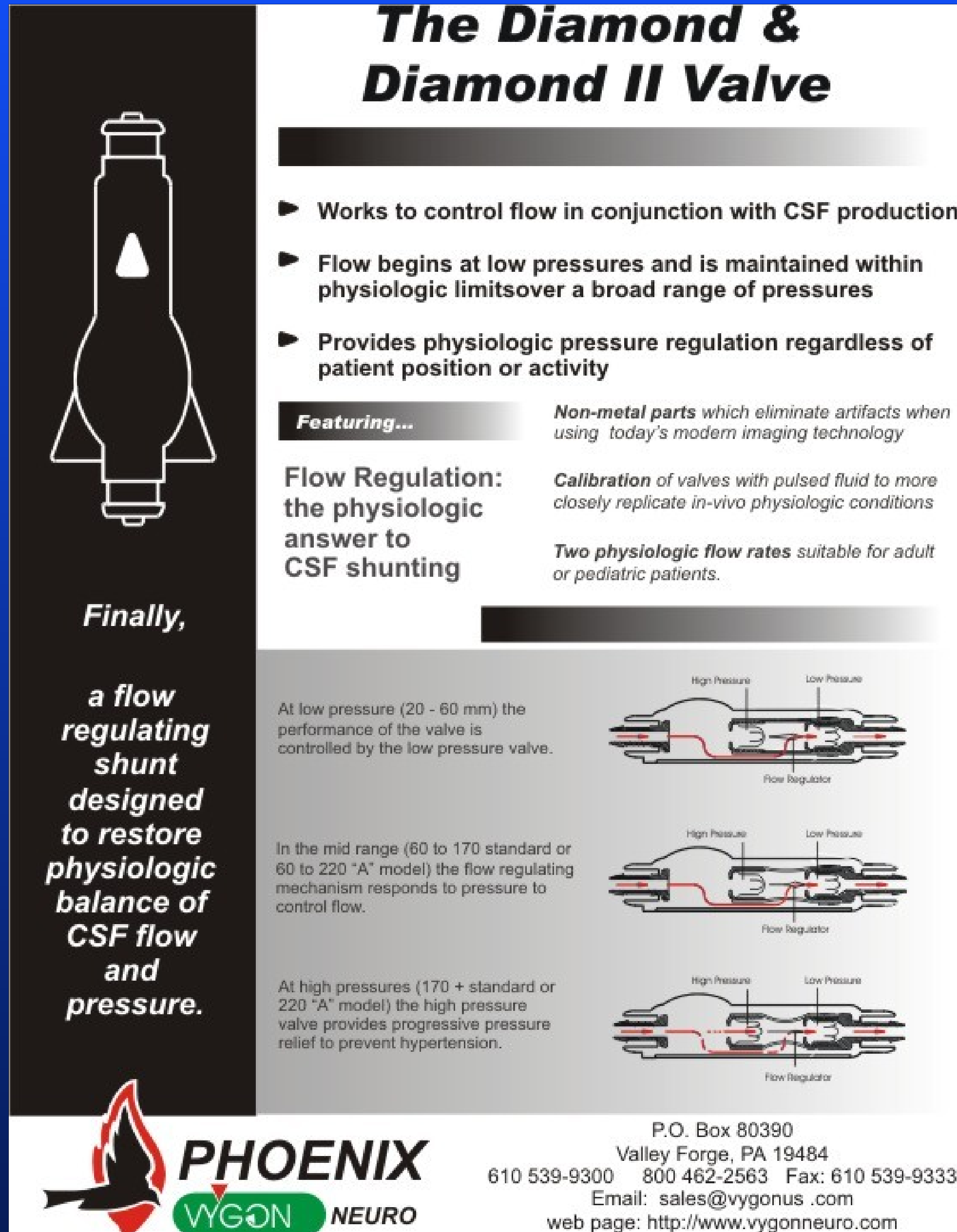


Adjustment and malfunction of a programmable valve after exposure to toy magnets. Case report.

Anderson RC, **Walker ML**, **Viner JM**, **Kestle JR**.

Inadvertent adjustments and malfunctions of programmable valves have been reported in cases in which patients have encountered powerful electromagnetic fields such as those involved in magnetic resonance imaging, but the effects of small magnetic fields are not well known. The authors present a case in which a child playing with a collection of commercially available toy magnets altered the pressure setting of an implanted valve and may have caused its permanent malfunction.

J Neurosurg. 2004 Nov;101(2 Suppl):222-5


The Diamond &
Diamond II Valve
Works to control flow in conjunction with CSF production
Flow begins at low pressures and is maintained within physiologic limitsover a broad range of pressures
Provides physiologic pressure regulation regardless of patient position or activity
Featuring...
Flow Regulation: the physiologic answer to CSF shunting
Non-metal parts which eliminate artifacts when using today's modern imaging technology
Calibration of valves with pulsed fluid to more closely replicate in-vivo physiologic conditions
Two physiologic flow rates suitable for adult or pediatric patients.
Finally,
a flow regulating shunt designed to restore physiologic balance of CSF flow and pressure.
At low pressure (20 - 60 mm) the performance of the valve is controlled by the low pressure valve.
High Pressure
Low Pressure
Flow Regulator
In the mid range (60 to 170 standard or 60 to 220 "A" model) the flow regulating mechanism responds to pressure to control flow.
High Pressure
Low Pressure
Flow Regulator
At high pressures (170 + standard or 220 "A" model) the high pressure valve provides progressive pressure relief to prevent hypertension.
High Pressure
Low Pressure
Flow Regulator
PHOENIX
VYGON NEURO
P.O. Box 80390
Valley Forge, PA 19484
610 539-9300 800 462-2563 Fax: 610 539-9333
Email: sales@vygonus .com
web page: http://www.vygonneuro.com

Laboratory evaluation of the phoenix CRx diamond valve.Czosnyka ZH, Czosnyka M, Richards HK, Pickard JD.

Neurosurgery. 2001 Mar;48(3):689-93; discussion 693-4. Links

United Kingdom Shunt Evaluation Laboratory, Academic Neurosurgical Unit, Addenbrooke's Hospital, Cambridge, England. zc200@medschl.cam.ac.uk

OBJECTIVE: To assess the long-term hydrodynamic properties of a new cerebrospinal fluid flow-regulating hydrocephalus shunt called the CRx Diamond valve (Phoenix Biomedical Corp., Valley Forge, PA). METHODS: Three samples of a Diamond valve were tested in the United Kingdom Shunt Evaluation Laboratory during a 40-day period. Tests were performed for long-term pressure-flow performance, overdrainage, susceptibility to ambient temperature changes, external pressure, reflux, presence of small particles in the reagent, mechanical durability, and magnetic resonance imaging compatibility. RESULTS: Tests demonstrated that the Diamond valve stabilized flow within the range of 0.36 to 0.62 ml/min when pressure varied from 14 to 23 mm Hg. Hydrodynamic resistance demonstrated pressure-dependent variability from 20 to 78 mm Hg/(ml/min). The time drift of hydrodynamic parameters was significant ($P < 0.001$). The valve was insensitive to changes in temperature, external pressure, rapid fluctuations of differential pressure, small particles in fluid, and reflux. CONCLUSION: **The Diamond valve demonstrated the intended variable resistance**, which increased as the pressure increased. This property may help it limit overdrainage related to body posture as well as nocturnal vasogenic waves. Flow through the valve stabilizes within a wide range, which may contribute to the prevention of excessive pressure buildup after implantation. However, shunt placement should be avoided in patients who present with normal baseline intracranial pressure but an increased incidence of high vasogenic intracranial pressure waves.

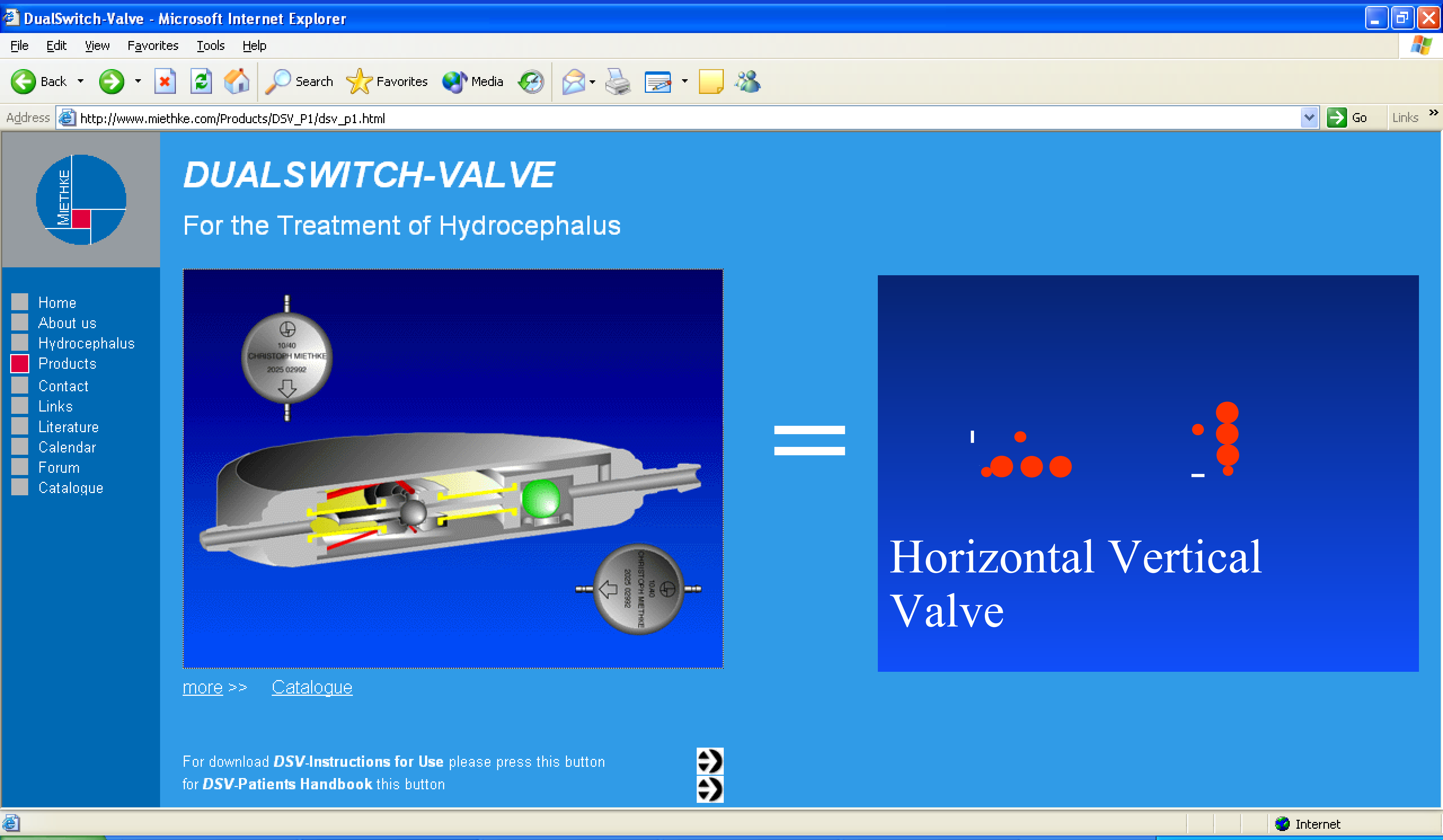
A new self-adjusting flow-regulating device for shunting of CSF.Paes N. Clinica de Coluna, University of Mogi das Cruzes, Tatuape, Sao Paulo, Brazil. Childs Nerv Syst. 1996 Oct;12(10):619-25.

Traditional shunts were primarily designed to manage hydrocephalus by regulating intracranial pressure. However, in some circumstances, their performance characteristics can cause them to underdrain or overdrain CSF. Overdrainage has been linked with clinical complications such as valve-dependent shunt syndrome, cranial stenosis, slit-ventricle syndrome, and subdural hematomas, and it may contribute to ventricular catheter occlusion. In addition to complications associated with hypertension and ventriculomegaly, underdrainage has been linked with residual brain edema, and subcutaneous CSF effusion has been observed at the site of cranial perforation, mainly in pediatric patients. Newer designs attempt to reduce these complications, but fall short for various reasons. The author presents a new shunt design, which utilizes variable aperture technology (patent pending) that results in the physiologic regulation of CSF flow under both positive and negative pressure conditions. This new design offers encouragement for the management of hydrocephalus and the prevention of complications due to overdrainage.

The Shunt "Rep" Most Telling Comment

- Me "your child needs a shunt for failed third ventriculostomy, post infectious hydrocephalus"
- Rep "Just don't put in any of that junk that (company they formally worked for) makes"

Miethke Dual Switch Valve



Evaluation of three new models of hydrocephalus shunts.

Czosnyka ZH, Czosnyka M, Richards HK, Pickard JD.
Academic Neurosurgical Unit, Addenbrooke's Hospital, Cambridge, UK.

OBJECTIVE: To assess the hydrodynamic properties of three new types of hydrocephalus valve. METHODS: Three new constructions have been recently tested in the UK shunt Evaluation Laboratory: the magnetically adjustable **Strata Valve** (Medtronic PS Medical), the gravitational **Miethke Dual-Switch Valve** (Aesculap) and the ventriculo-sinus **SinuShunt** (CSF Dynamics). Pressure-flow performance curves were assessed in a minimum of three samples of each valve to study their longterm variability, influence of temperature, negative outlet pressure, external pressure, presence of pressure pulsations, etc. RESULTS: The operating pressure of the Strata Valve can be adjusted magnetically in five steps. This Shunt prevents 'siphoning' but is sensitive to external pressure. The Dual Switch Miethke Valve is a system of two fixed-pressure ball-on-spring valves with a lower opening pressure operating in a horizontal body position and higher when vertical. This function is designed to cancel the effect of siphoning related to body posture. Both Strata and DSV valves have a low hydrodynamic resistance (less than 3 mm Hg/ml/min), and hence they cannot prevent overdrainage related to nocturnal vasomotor waves. The SinuShunt has a higher resistance (9 mm Hg/(ml/min)) and a lower opening pressure. The valve is intended to drain CSF from ventricles to the transverse sinus. CONCLUSION: New shunt technology continues to evolve. Laboratory evaluation independent of the manufacturer forms an important link between R&D laboratories and clinical practice.

Acta Neurochir Suppl. 2005;95:223-7

Miethke Dual Switch Valve – Pub Med 22 refs

1. Meier U, Kiefer M, Neumann U, Lemcke J. Related Articles, Links
On the optimal opening pressure of hydrostatic valves in cases of idiopathic normal-pressure hydrocephalus: a prospective randomized study with 123 patients. Acta Neurochir Suppl. 2006;96:358-63.

2: Sprung C, Miethke C, Schlosser HG, Brock M
The enigma of underdrainage in shunting with hydrostatic valves and possible solutions. Acta Neurochir Suppl. 2005;95:229-35.

3: Czosnyka ZH, Czosnyka M, Richards HK, Pickard JD. Related Articles, Links
Evaluation of three new models of hydrocephalus shunts. Acta Neurochir Suppl. 2005;95:223-7.

4: Meier U. Gravity valves for idiopathic normal-pressure hydrocephalus: a prospective study with 60 patients. Acta Neurochir Suppl. 2005;95:201-5.

5: Lindner D, Preul C, Trantakis C, Moeller H, Meixensberger J.
Effect of 3T MRI on the function of shunt valves--evaluation of Paedi GAV, Dual Switch and proGAV. Eur J Radiol. 2005 Oct;56(1):56-9.

The Polaris® Valve

Dutch Normal-Pressure Hydrocephalus Study: randomized comparison of low- and medium-pressure shunts

Boon AJ, Tans JT, Delwel EJ, Egeler-Peerdeman SM, Hanlo PW, Wurzer HA, Avezaat CJ, de Jong DA, Gooskens RH, Hermans J. J Neurosurg. 1998 Mar;88(3):490-5. Links

OBJECT: The goal of this prospective study was to compare outcome after placement of a low- or medium-pressure shunt in patients with normal-pressure hydrocephalus (NPH). METHODS: Ninety-six patients with NPH were randomized to receive a low-pressure ventriculoperitoneal shunt (LPV; 40 +/- 10 mm H2O) or medium high-pressure ventriculoperitoneal shunt (MPV; 100 +/- 10 mm H2O). The patients' gait disturbance and dementia were quantified by applying an NPH scale, and their level of disability was evaluated by using the modified Rankin scale (mRS). Patients were examined prior to and 1, 3, 6, 9, and 12 months after surgery. Primary outcome measures were determined by differences between preoperative and last NPH scale scores and mRS grades. The LPV and MPV shunt groups were compared by calculating both the differences between mean improvements and the proportions of patients showing improvement. Intention-to-treat analysis of mRS grades yielded a mean improvement of 1.27 +/- 1.41 for patients with LPV shunts and 0.68 +/- 1.58 for patients with MPV shunts **(p = 0.06).** Improvement was found in 74% of patients with LPV shunts and in 53% of patients with MPV shunts **(p = 0.06)** and a marked-to-excellent improvement in 45% of patients with LPV shunts and 28% of patients with MPV shunts **(p = 0.12).** All outcome measures indicated trends in favor of the LPV shunt group, with only the dementia scale reaching significance. After exclusion of serious events and deaths unrelated to NPH, **efficacy analysis showed the advantage of LPV shunts to be diminished.** Reduction in ventricular size was also significantly greater for patients in the LPV shunt group (p = 0.009). Subdural effusions occurred in 71% of patients with an LPV shunt and in 34% with an MPV shunt; however, their influence on patient outcome was limited. CONCLUSIONS: Outcome was better for patients who had an LPV shunt than for those with an MPV shunt, although most differences were not statistically significant. **The authors advise that patients with NPH be treated with an LPV shunt.**

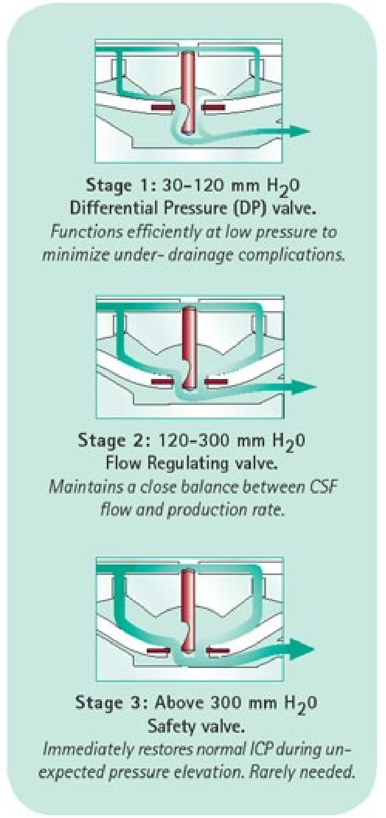
INPH GUIDELINES, PART IV

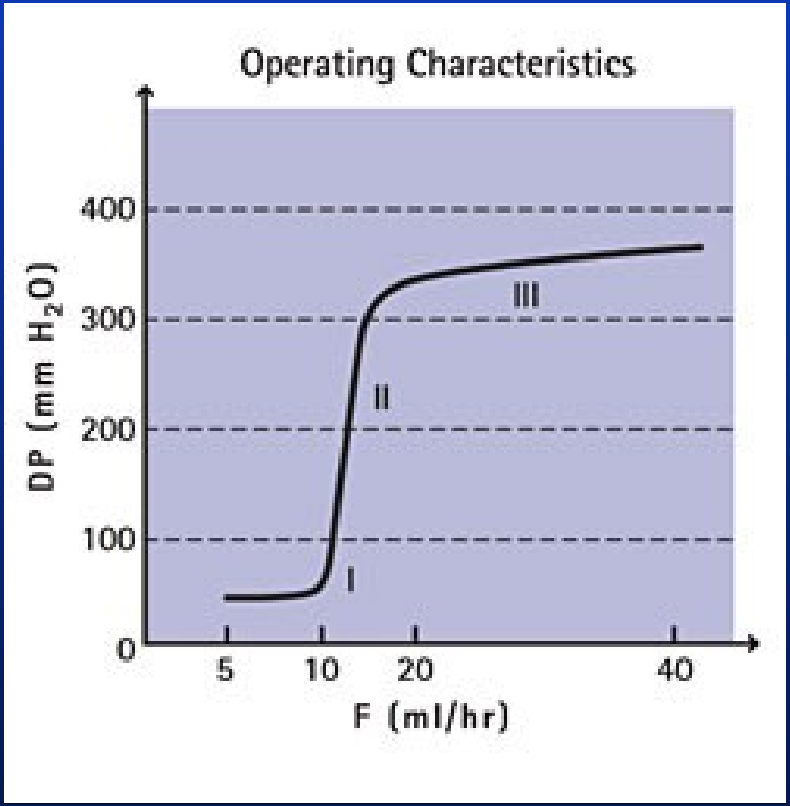
Surgical Management of Idiopathic Normal-pressure Hydrocephalus

NEUROSURGERY

… The choice of valve type and setting should be based on empirical reasoning and a basic understanding of shunt hydrodynamics. The most conservative choice is a valve incorporating an antisiphon device, with the understanding that underdrainage (despite a low opening pressure) may occur in a small percentage of patients because of the antisiphon device. On the basis of retrospective studies, the use of an adjustable valve seems to be beneficial in the management of INPH.

The Integra NPH Low Flow Valve





Assessment of low-flow CSF drainage as a treatment for AD: results of a randomized pilot study.

Silverberg GD, Levinthal E, Sullivan EV, Bloch DA, Chang SD, Leverenz J, Flitman S, Winn R, Marciano F, Saul T, Huhn S, Mayo M, McGuire D.

OBJECTIVE: This prospective, randomized, controlled study was designed to investigate the safety, feasibility, and preliminary efficacy of long-term CSF drainage via a low-flow ventriculoperitoneal shunt in subjects suffering from AD. METHODS: Twenty-nine subjects selected for probable AD (National Institute of Neurological and Communicative Diseases and Stroke-Alzheimer's Disease and Related Dementias Association criteria) were screened to exclude normal pressure hydrocephalus or other etiologies of dementia and randomized to treatment (shunt) or no treatment groups. The study endpoint was the comparison of group performance on psychometric testing at quarterly intervals for 1 year. Shunted subjects had CSF withdrawn for MAP-tau and Abeta((1-42)) assays at the same time intervals. RESULTS: There was no mortality from the surgical procedure, and no patient sustained a subdural hematoma. Five notable postoperative adverse events, which resolved without permanent neurologic deficit, were reported in the shunt group. Group mean Mattis Dementia Rating Scale total scores showed little change over the year in the shunt-treatment group, in contrast to a decline in the control group ($p = 0.06$). Mini-Mental State Examination mean scores supported a trend in favor of shunt treatment ($p = 0.1$). There was a concomitant decrease in ventricular CSF concentrations of AD biomarkers MAP-tau and Abeta((1-42)). CONCLUSIONS: The surgical procedure and the device are reasonably safe. Adverse events were consistent with shunt procedures for hydrocephalus in this older population. The endpoint data show a trend in favor of the treated group. A larger, randomized, double-blinded, controlled, clinical trial is underway.

Neurology. 2002 Oct 22;59(8):1139-45

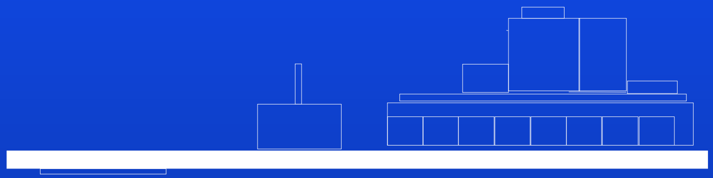
COGNIShunt® System for Alzheimer's Disease

This study has been completed.

Sponsored by:	**Eunoe**
Information provided by:	National Institute on Aging (NIA)
ClinicalTrials.gov Identifier:	NCT00056628

Based on the encouraging preliminary data, Eunoe entered into a pivotal study that eventually recruited 215 patients at 22 sites. On December 8, 2003, enrollment to the **study was halted** by the company based on the results of a planned interim analysis.

On June 14, 2004, the **study was closed** based on the results of the second interim analysis which showed that the difference between treatment groups for the MDRS, while still favoring the COGNIShunt group, was less than that of the first interim analysis.



Nulsen and Spitz -
Original Ball Valve

Medos Valve

Diaphragm valve

Delta Valve

Anti-siphon
device

Orbis Sigma

Horizontal Vertical
Valve

Valve Design Cycle

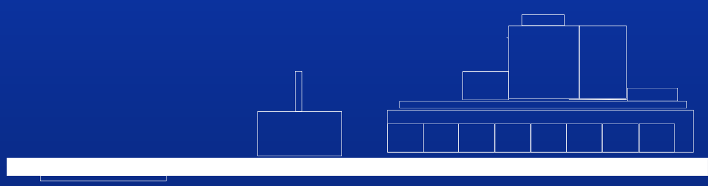
- Innovation often based on concept of improved “physiological function”
- Exciting early results
- Failure of Efficacy on prospective evaluation
- Unanticipated Consequences

Shunt Technology

- Balls
- springs
- diaphragms
- slit valves

→

- Implanted sensors
- communications interface
- microprocessor control
- MEMS technology



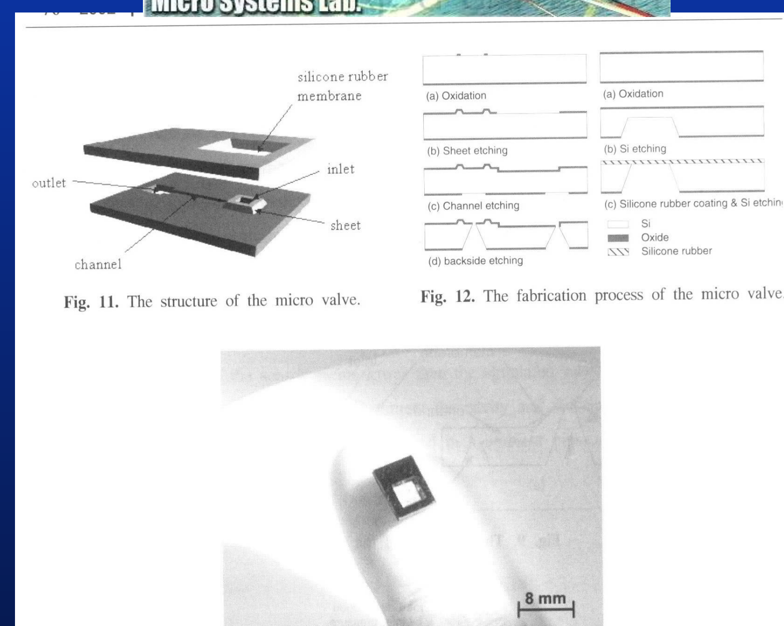


Fig. 11. The structure of the micro valve.

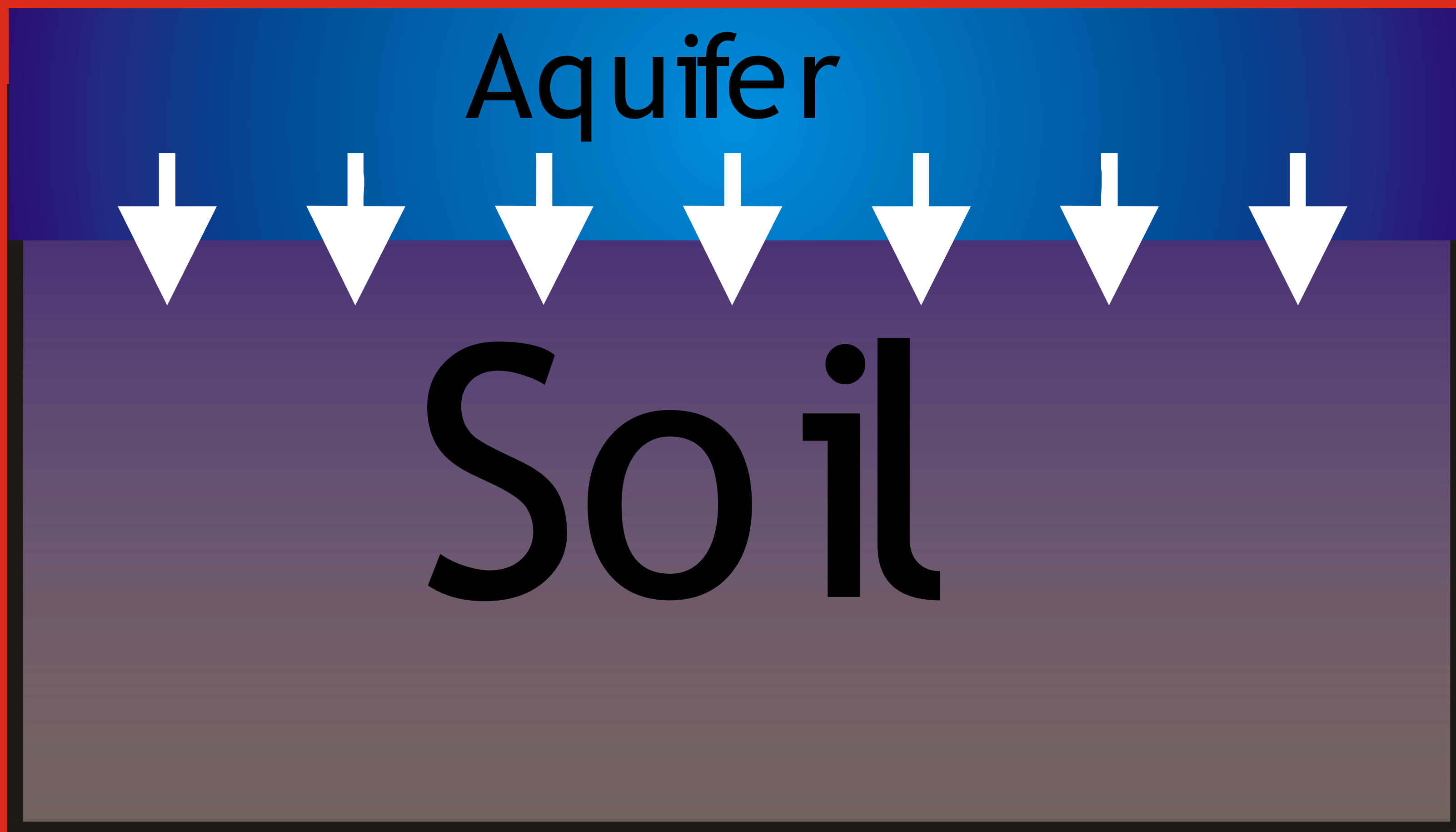
Fig. 12. The fabrication process of the micro valve.

Fig. 13. The photograph of the fabricated micro valve.

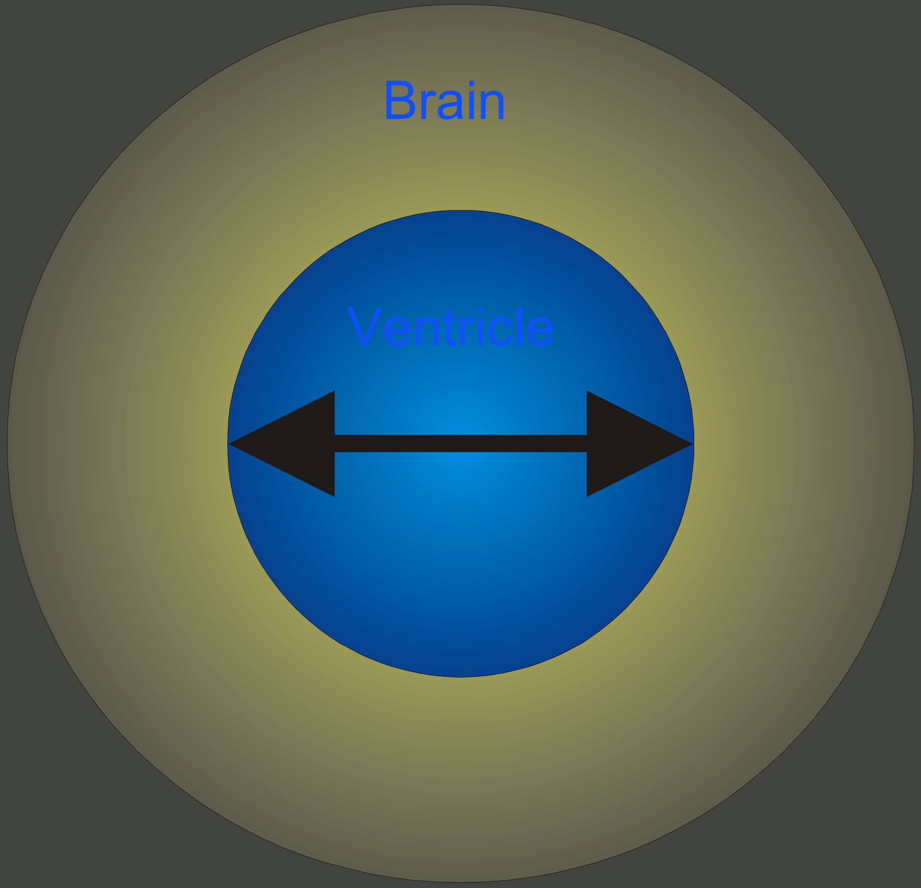
Consolidation Models

- Brain as a saturated sponge
- Flow through porous media
- Brain has visco-elastic properties
  - Will continue to deform at same pressure
  - Will not relax to baseline when pressure dropped

SOIL MECHANICS



CYLINDRICAL MODEL



Development of Model

Crucial step: Appropriate constitutive equation (stress v. strain), for instance:

(Hooke's Law)

$$\sigma_{ij} = \sum_{k=1}^{3} \sum_{l=1}^{3} C_{ijkl}\, e_{kl}$$

(General, linear elastic solid)

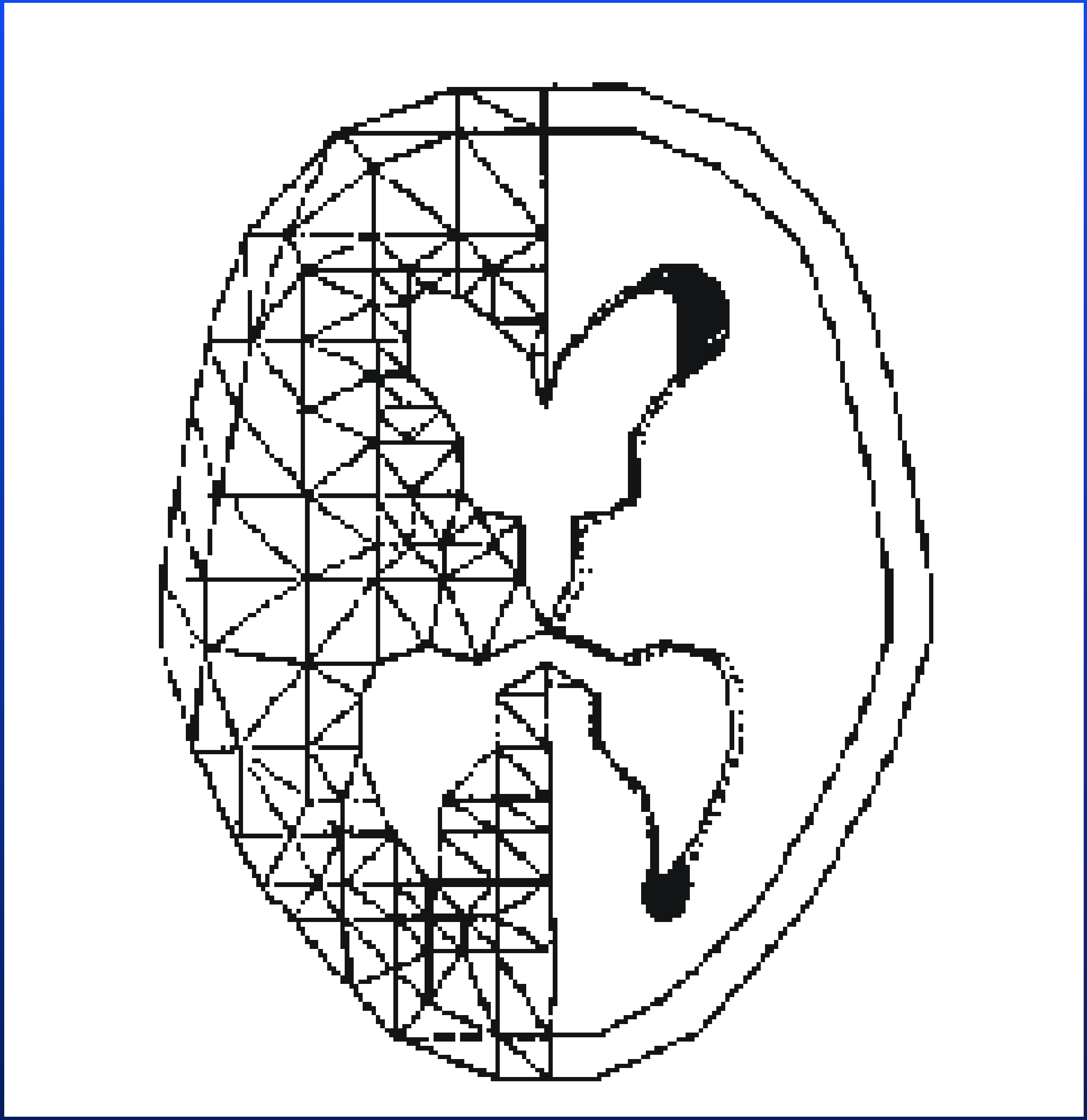
$$\sigma_{ij} = \lambda e \delta_{ij} + 2\mu\, e_{ij}$$

(Linear, isotropic solid)

$$\sigma_{ij}(r,t) = \int_{-\infty}^{t} \sum_{k,l=1}^{3} G_{ijkl}(t-\tau) \frac{\partial e_{kl}}{\partial \tau}(r,\tau)\, d\tau$$

(Linear viscoelastic)

Finite Element Analysis

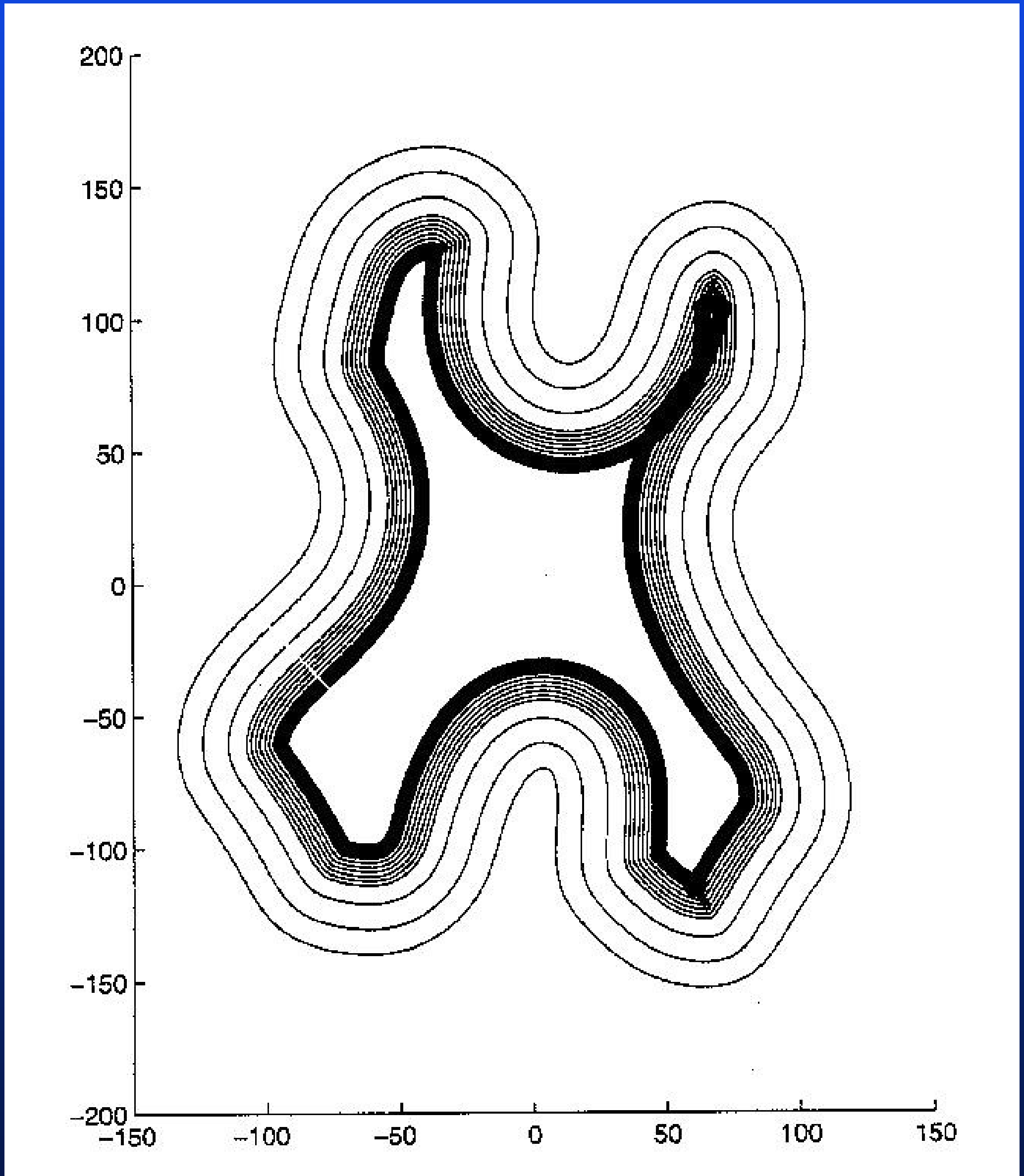


Nagashima 1990

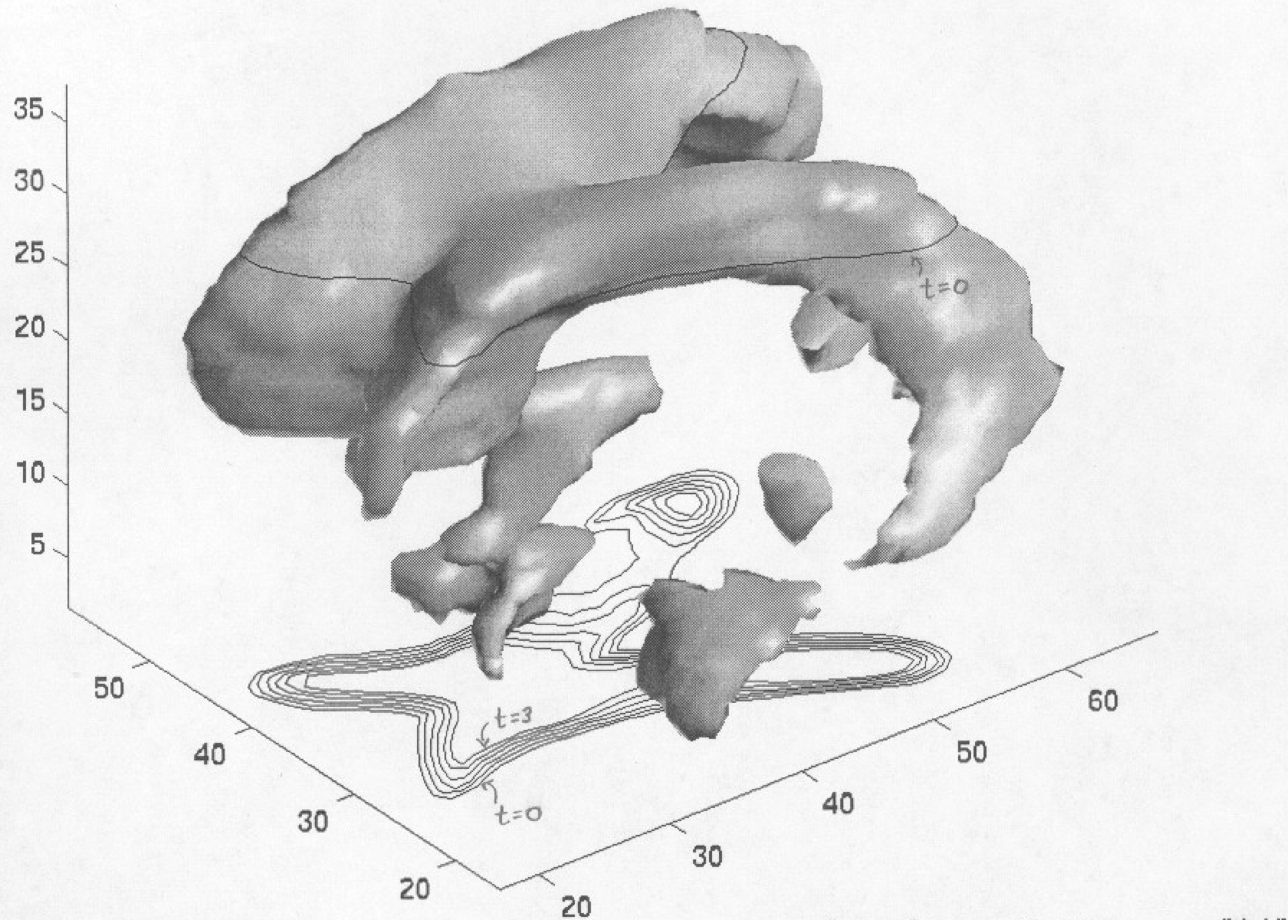
Consolidation Models

- Progress
  - Reasonable “early” predictions
    - Pressure distribution
    - Deformation
    - Fluid flow
  - Helpful estimate of Poisson ratio ~ .38 – stability of numerical simulations
- Limitations
  - Long time periods
  - Large deformations
  - Unknown brain parameters

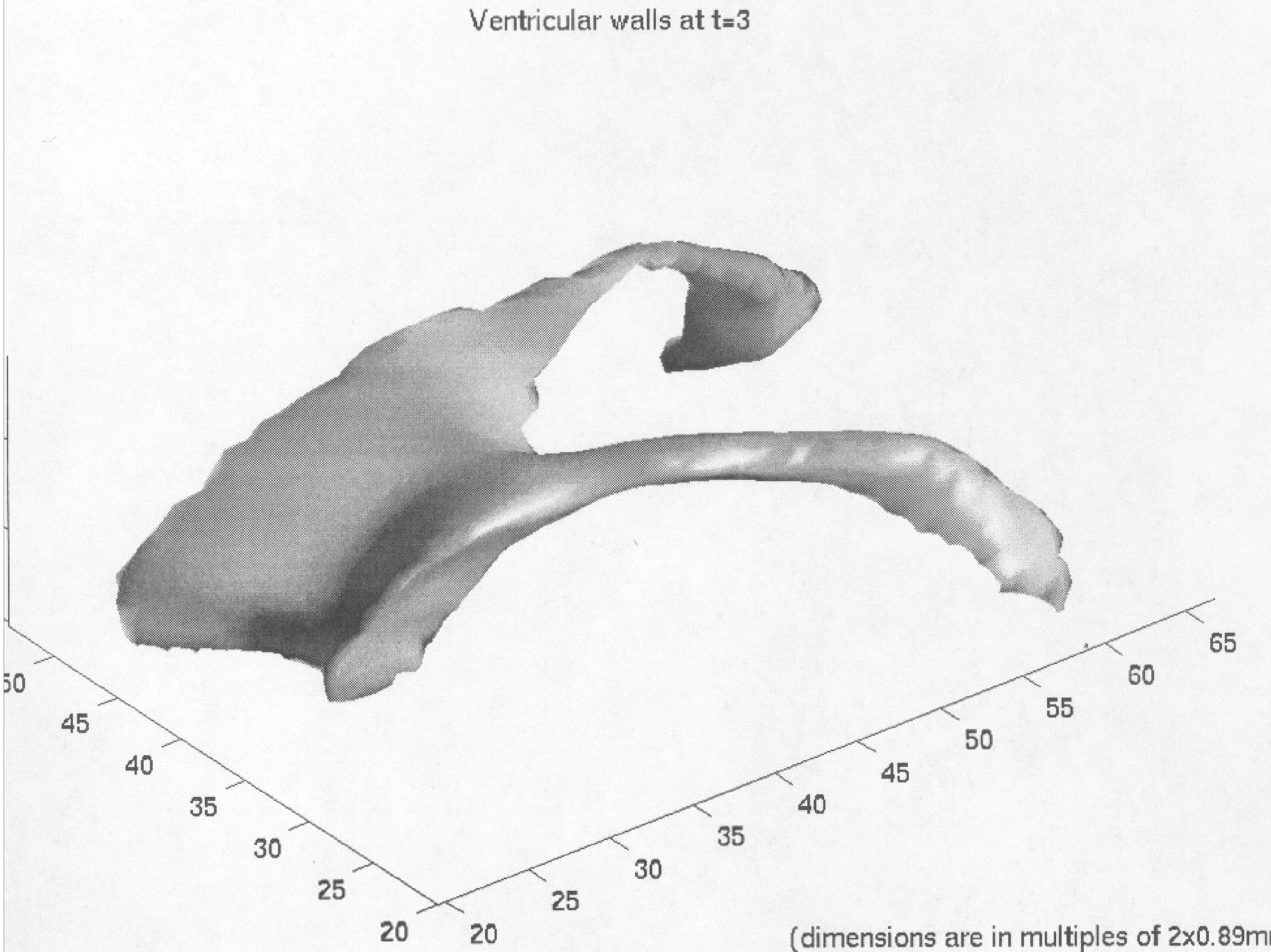
Ventricular Wall Motion Simulation (Elliptical Fourier Series)



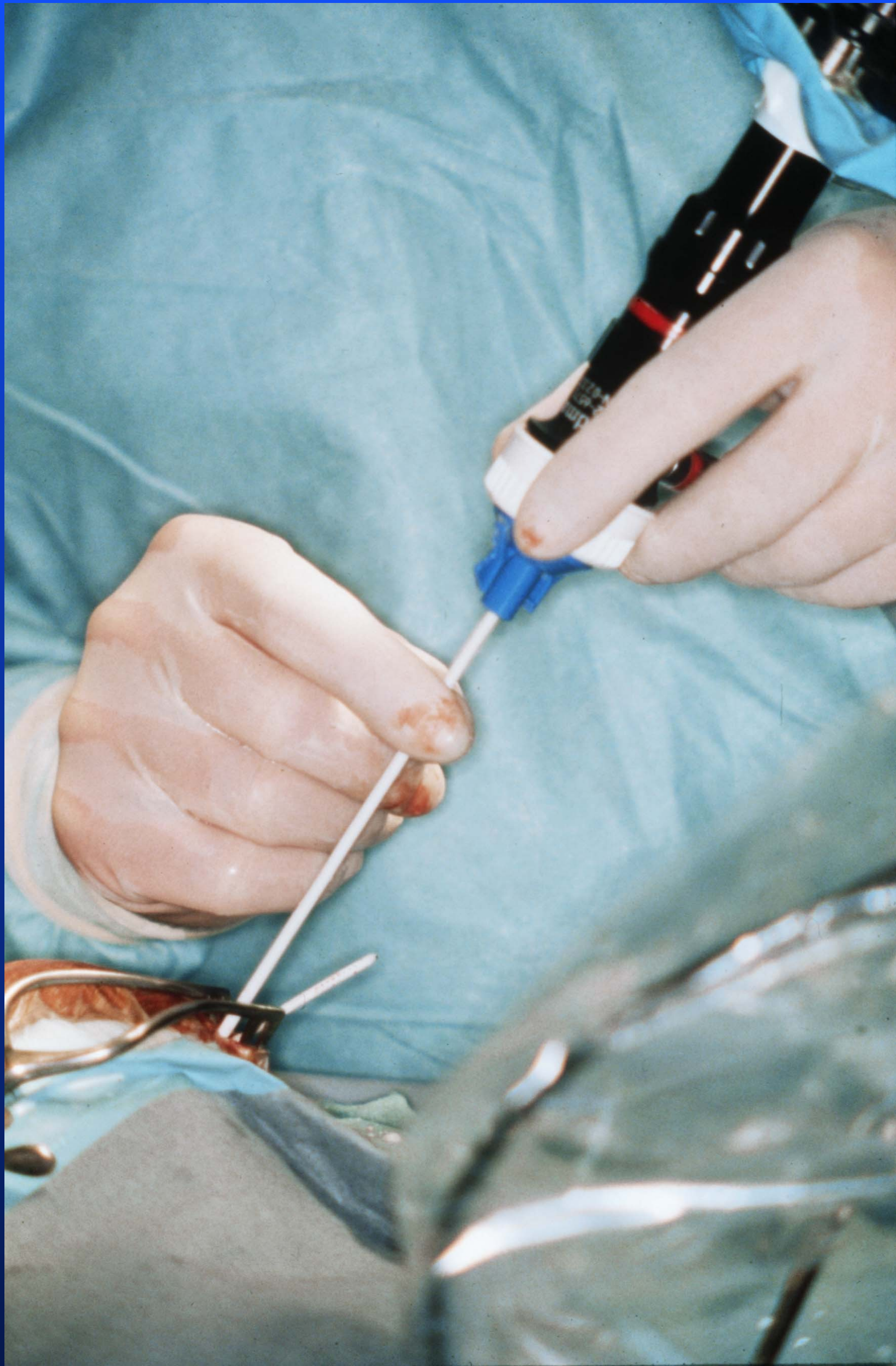
Ventricular walls at t=0, with cross sections for t=0..3 months, speed = −1mm/month



dimensions are 2x0.89mm per "tick"


Ventricular walls at t=3
50
45
40
35
30
25
20
20
25
30
35
40
45
50
55
60
65
(dimensions are in multiples of 2x0.89mm

- Accurate placement of the ventricular catheter reduces the shunt failure rate ?



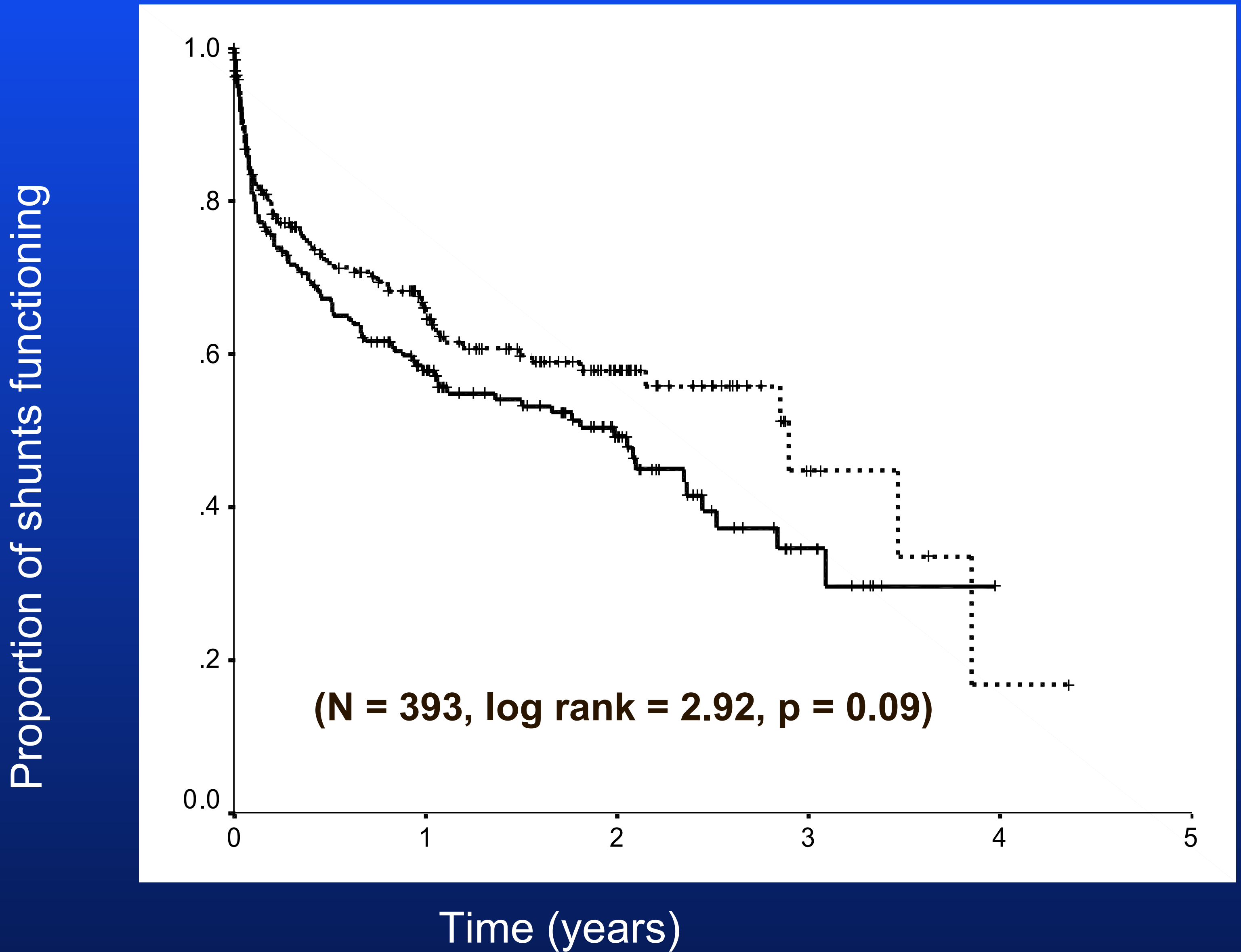
J Neurosurg 98:284–290, 2003

Lack of benefit of endoscopic ventriculoperitoneal shunt insertion: a multicenter randomized trial

JOHN R. W. KESTLE, M.D., JAMES M. DRAKE, M.D., D. DOUGLAS COCHRANE, M.D., RUTH MILNER, M.SC., MARION L. WALKER, M.D., RICK ABBOTT III, M.D., AND FREDERICK A. BOOP, M.D. FOR THE ENDOSCOPIC SHUNT INSERTION TRIAL PARTICIPANTS

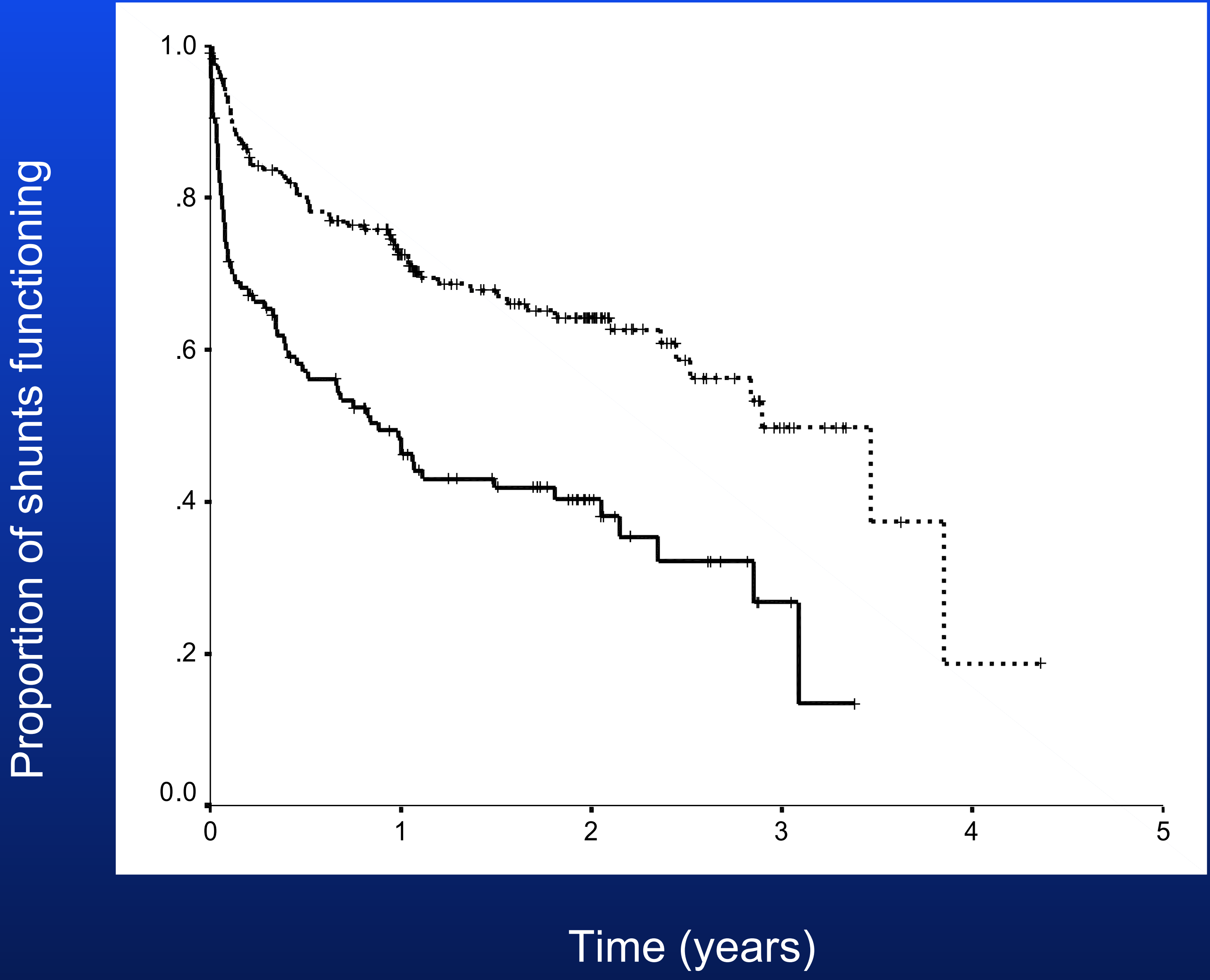
University of Utah, Primary Children's Medical Center, Salt Lake City, Utah; University of Toronto, The Hospital for Sick Children, Toronto, Ontario; University of British Columbia, British Columbia's Children's Hospital, Vancouver, British Columbia, Canada; Beth Israel Medical Center, New York, New York; and University of Tennessee, Memphis, Tennessee

Shunt survival in endoscope (——) and non endoscope (.........) groups

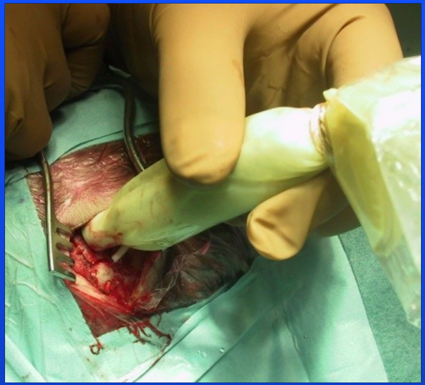
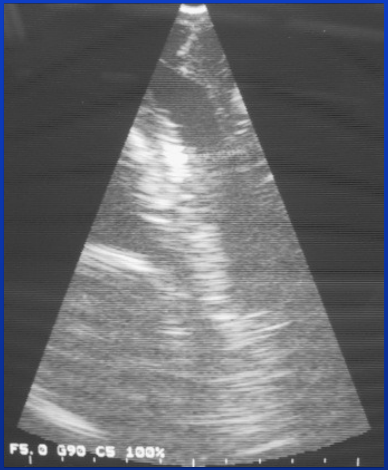


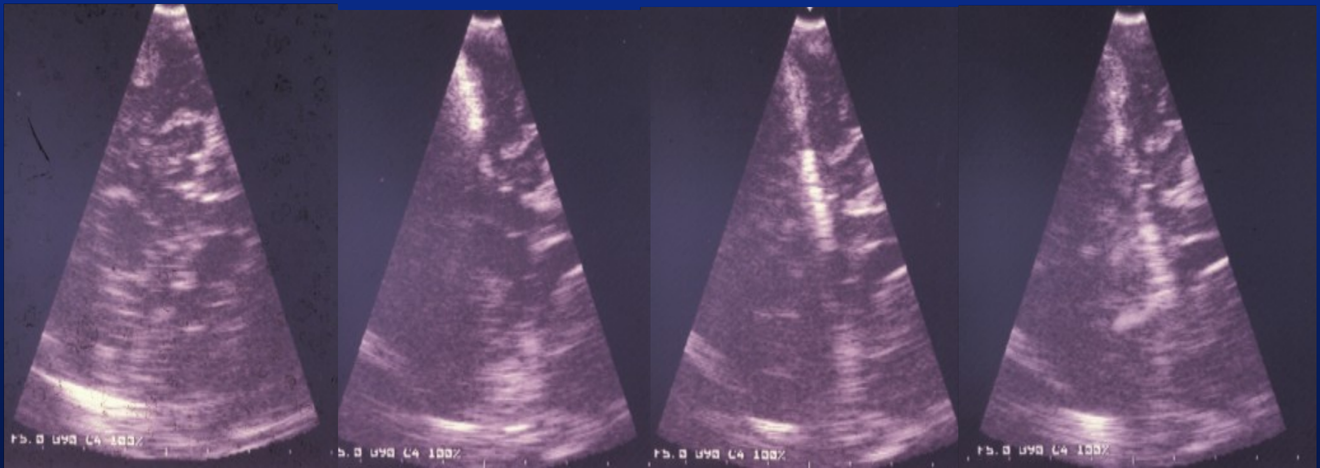
Kestle, Drake, Cochrane et al, J Neurosurgery, 2003

Ventricular catheter tip away (........) from choroid or not (——) at follow-up

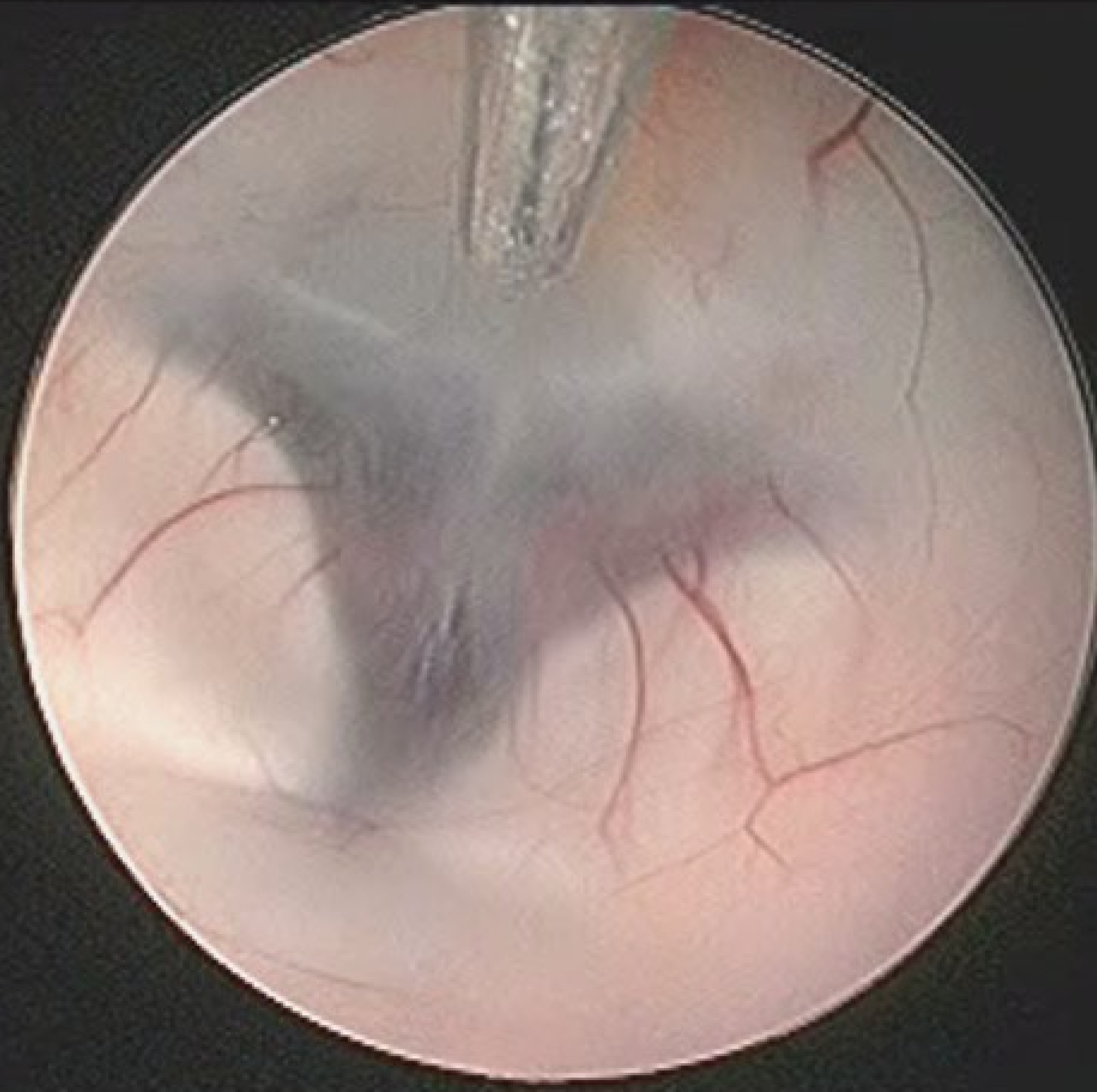


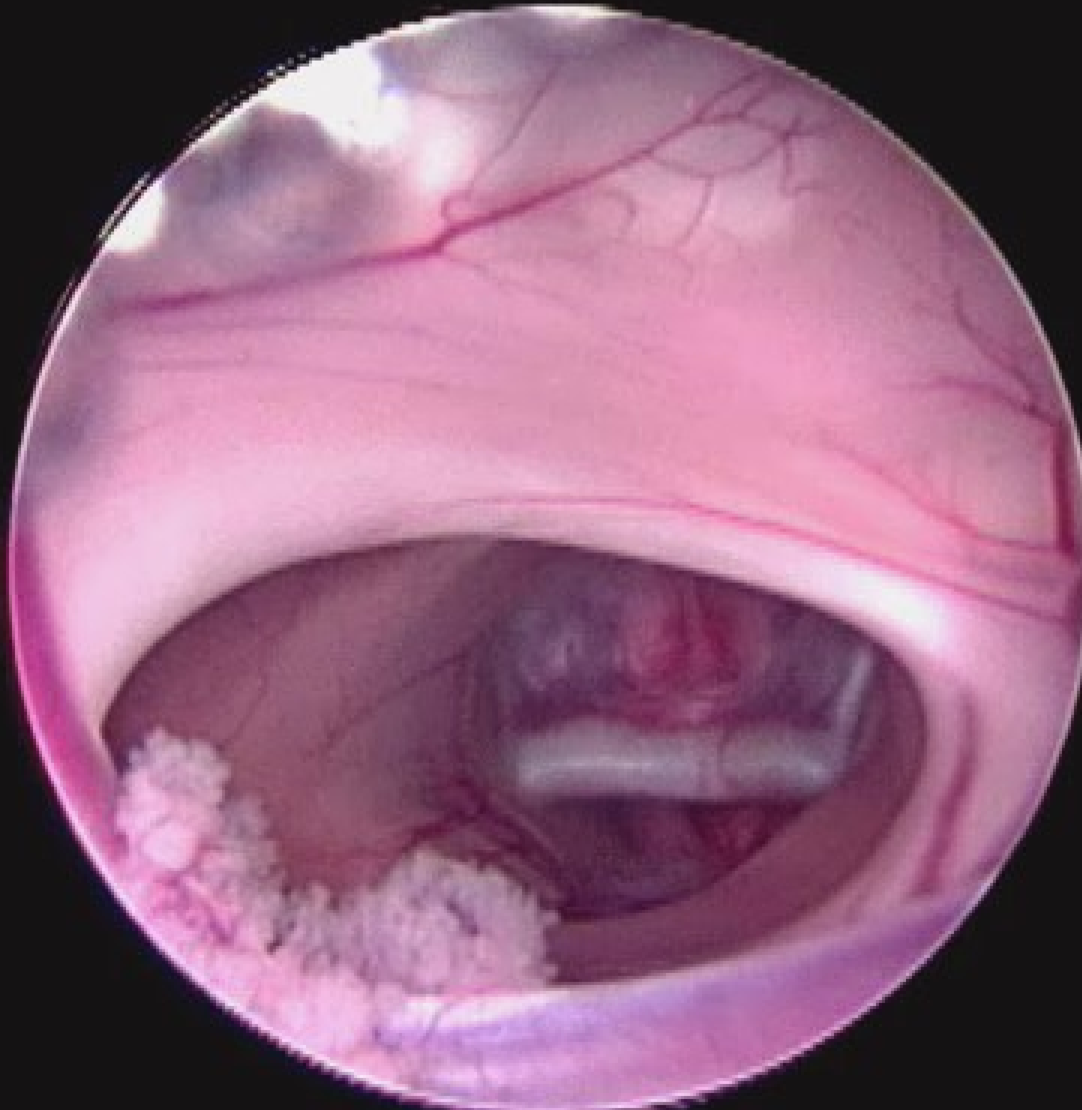
- **Operative Ultrasound**
  - Very user dependent
  - dynamic view of ventricles
  - catheter trajectory, path, tip position, hemorrhage, shunt function
  - small ventricles, loculated ventricles
  - ? every case

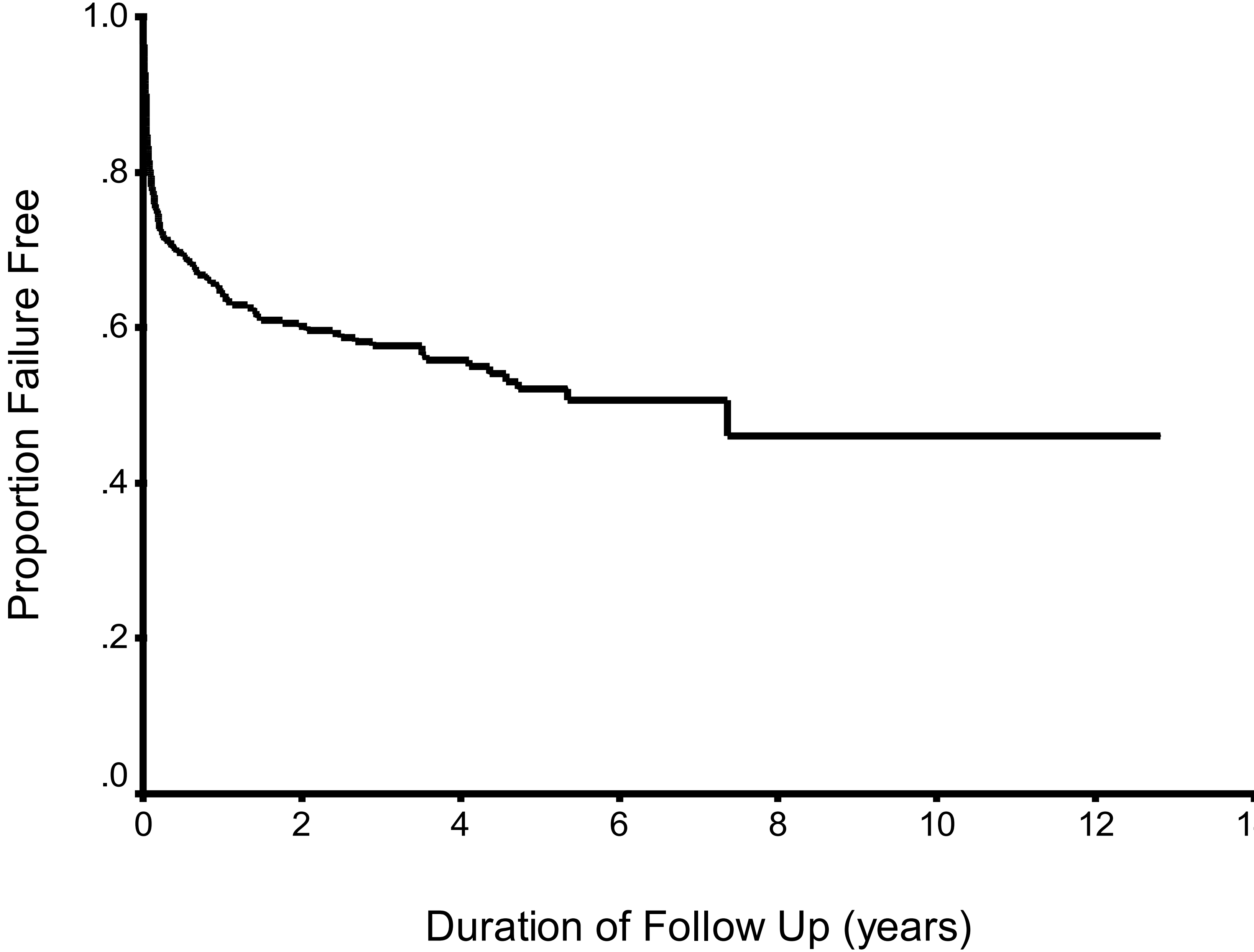




08:34:46
511/512
5.0
74Hz
DVA: 90%

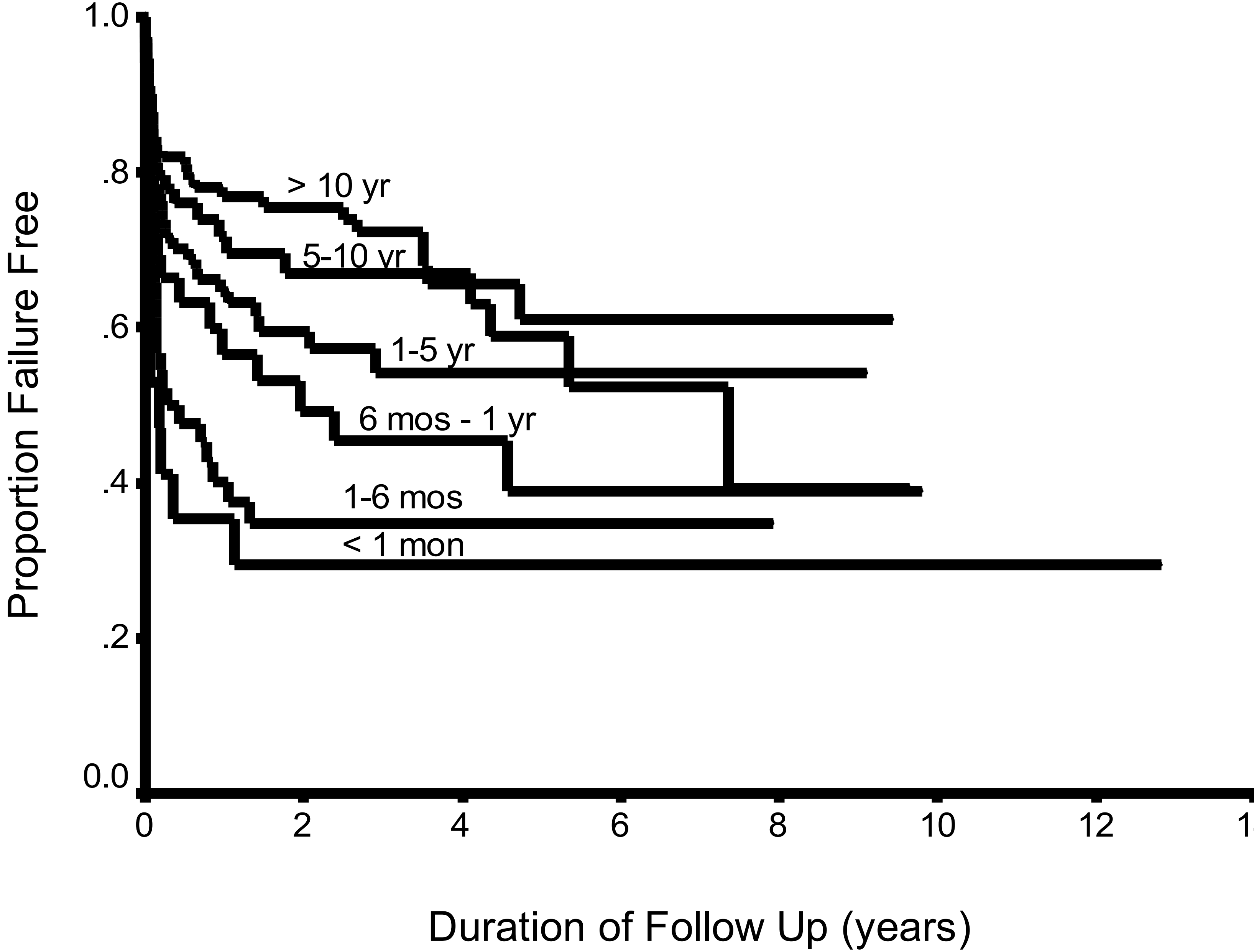




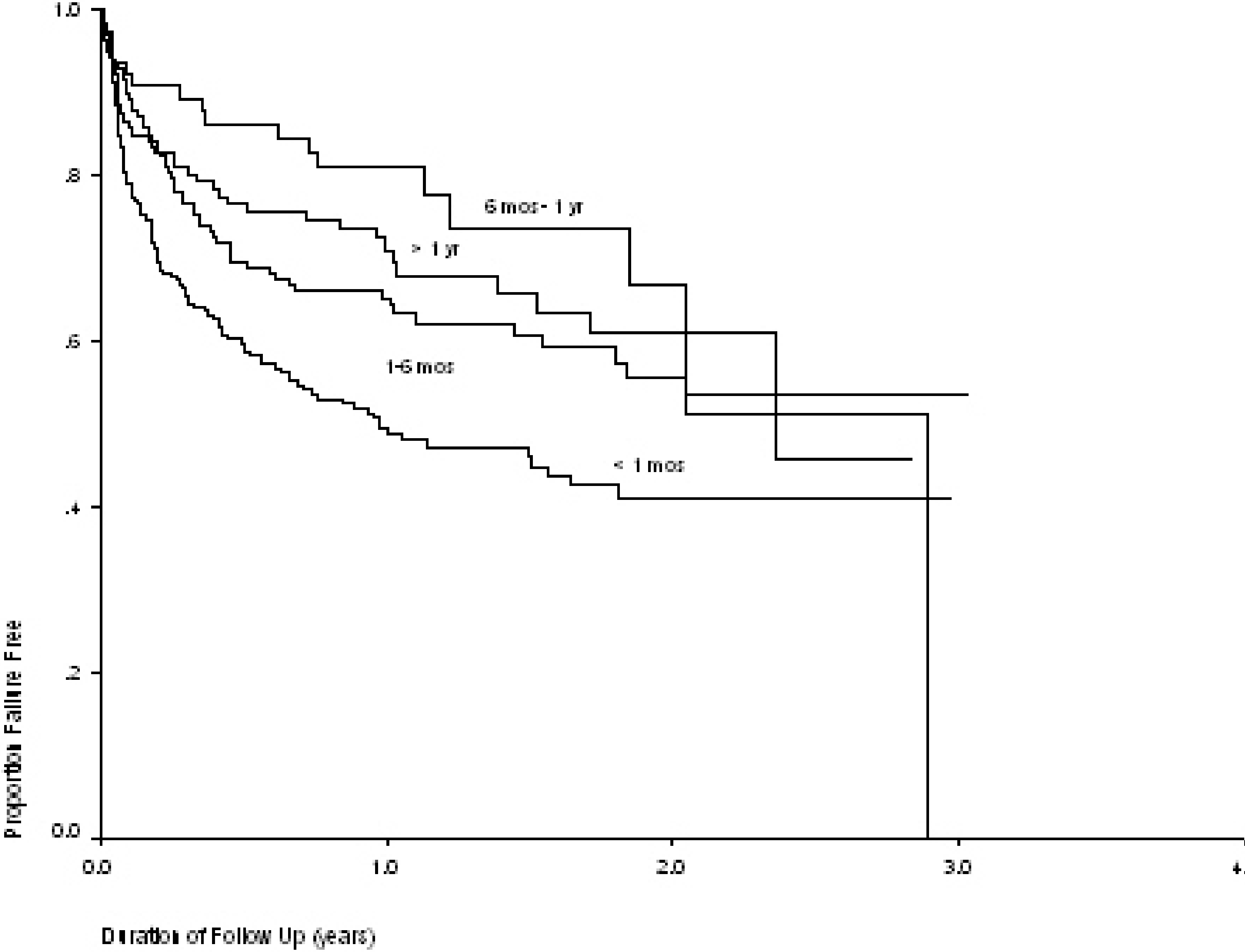
Failure Rate Overall (368 pts)



Failure Rate by Age Group

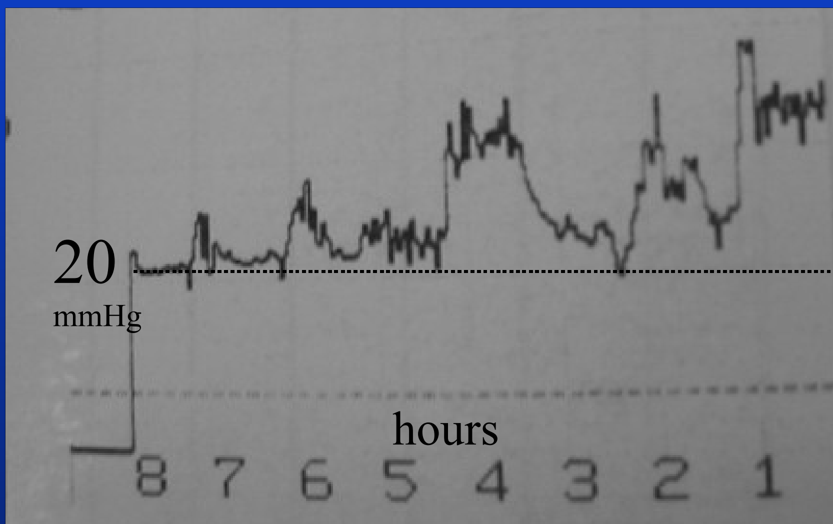


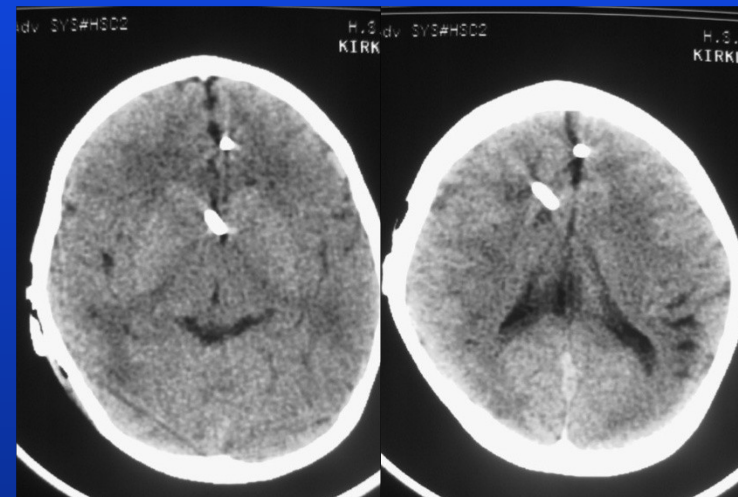
Shunt Failure Rate by Age Group

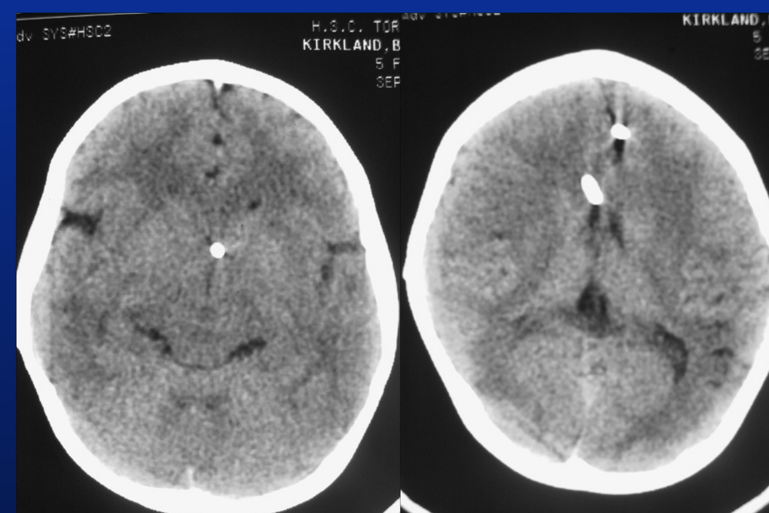


Slit Ventricle Syndrome

4 yr old, shaken baby
chronic headache, patent low pressure
shunt, several revisions

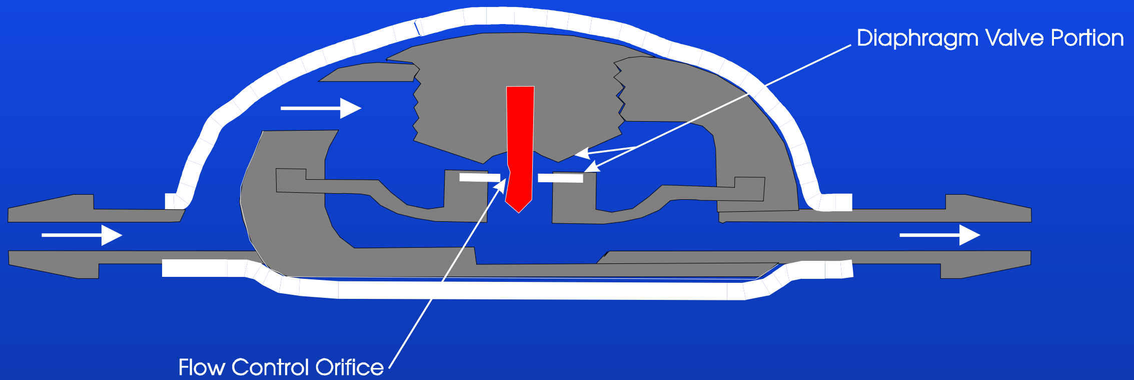






Orbis Sigma

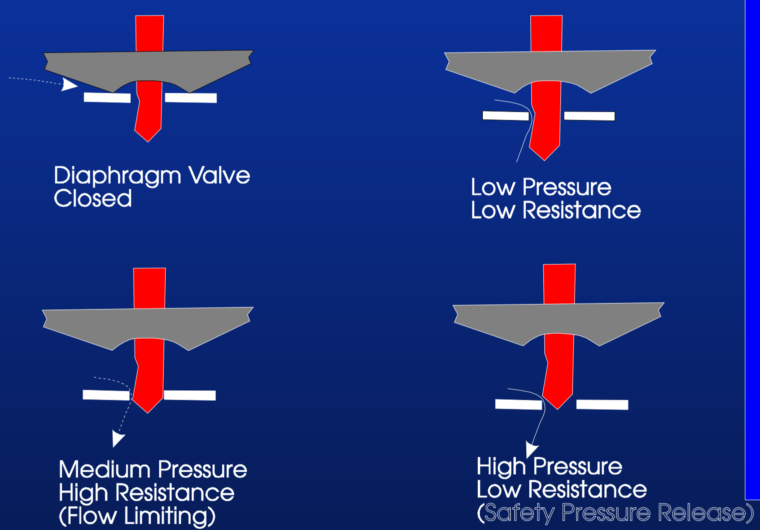
Cordis Orbis Sigma

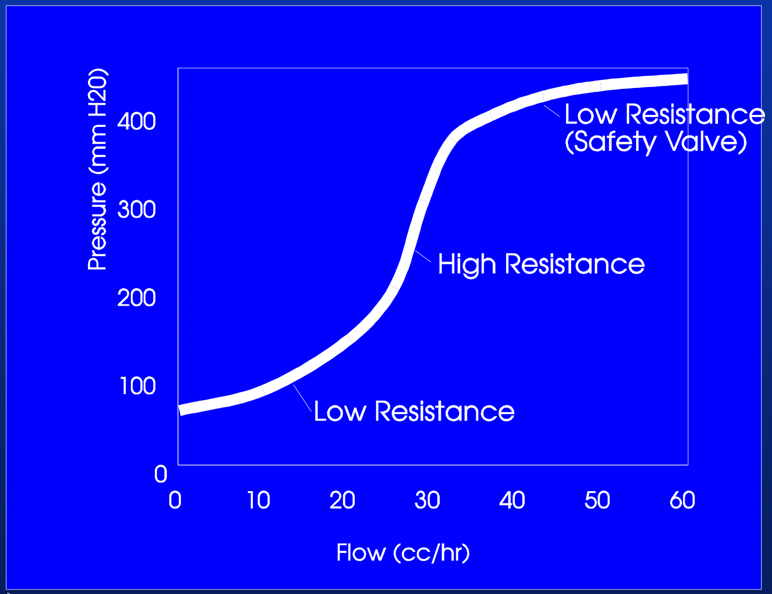


Mechanism

Pressure Flow Characteristics

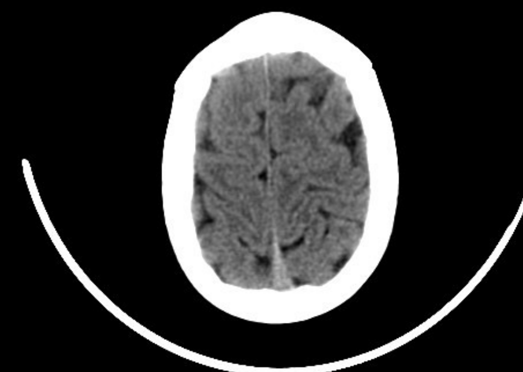
Variable Resistance Valve

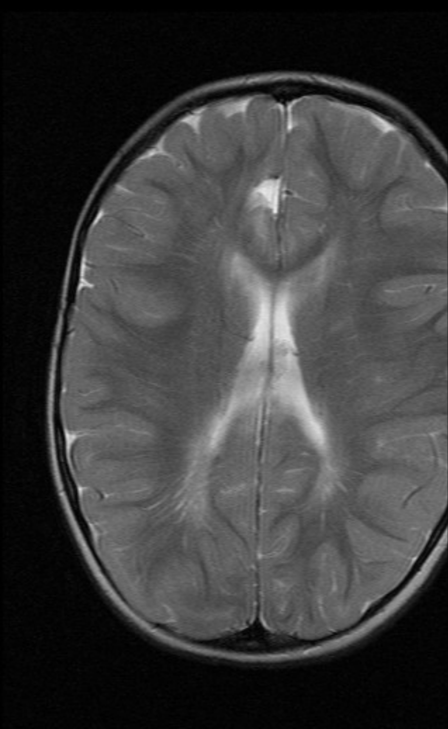




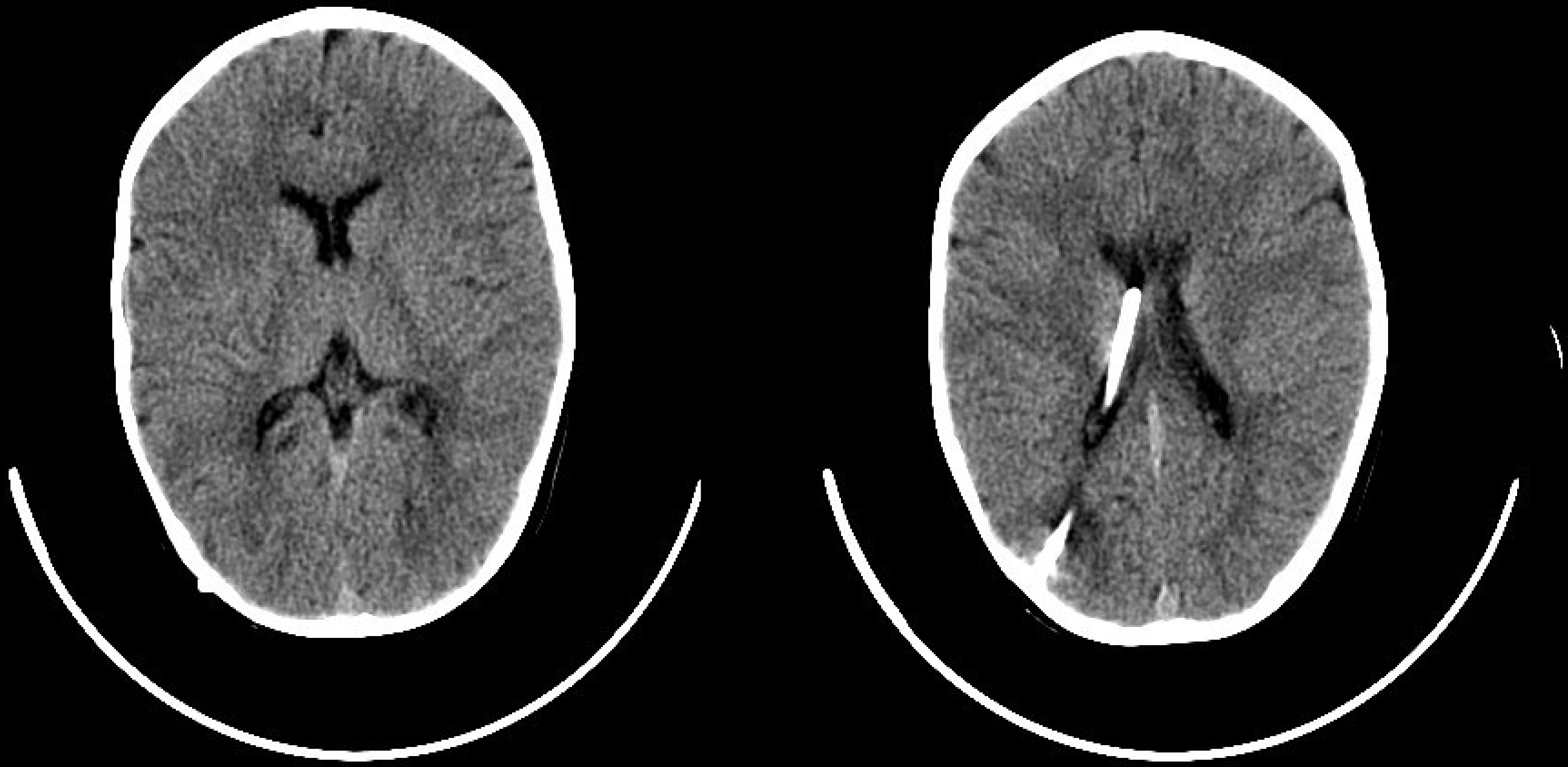
3.5 yr old boy, SAH, aneurysm age 7 mos, anterior cerebral artery, coiled, post SAH shunt. 6 mos Hx of irritability and vomiting, repeated hospital admissions other centre

? Cyclical vomiting



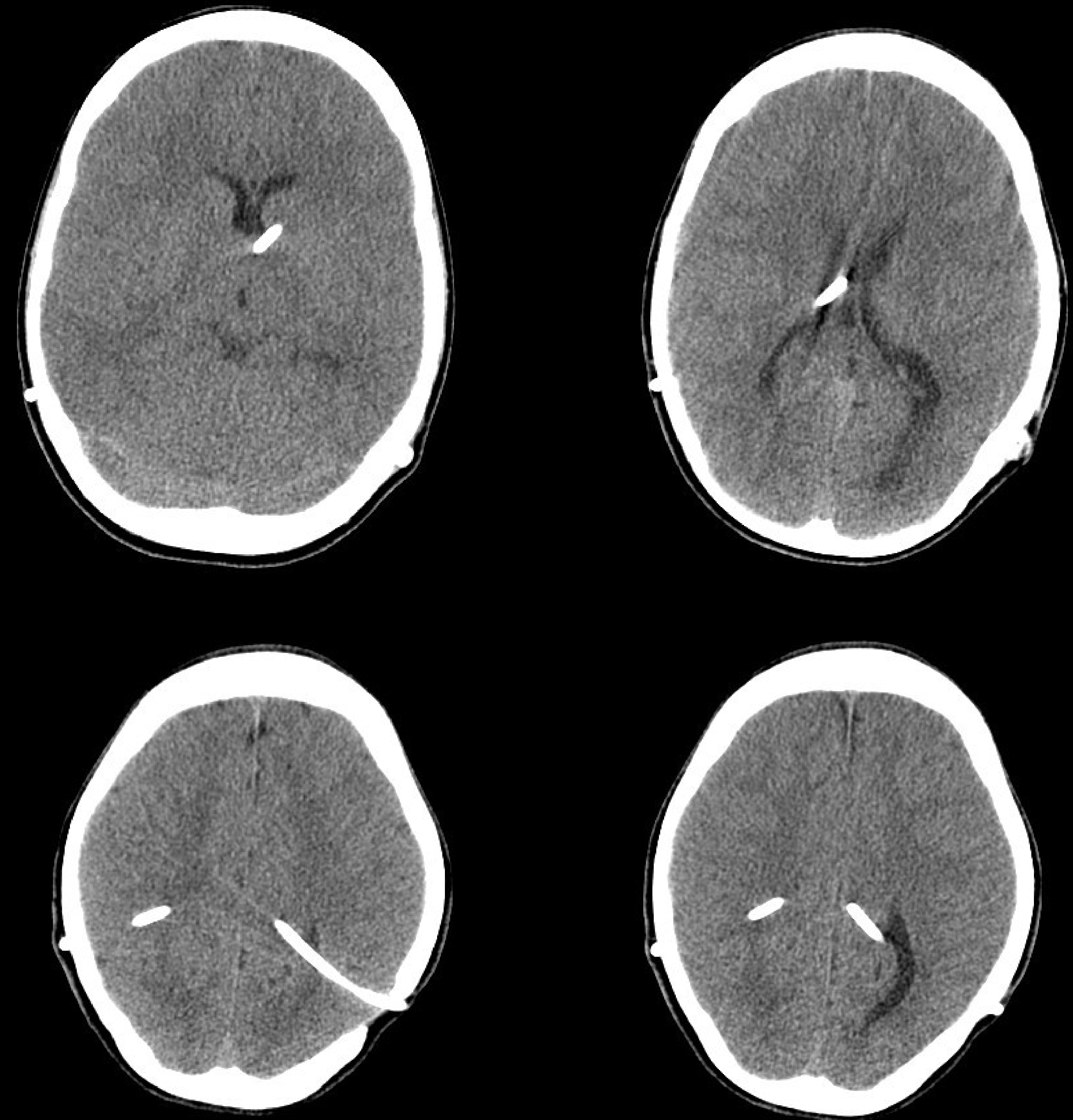


ICP monitor, ICP 40 mm Hg, leaking CSF from insertion site. Taken back to OR, shunt patent both ends, Orbis Sigma II valve change, gradual decline in pressure. 1 Revision 6 mos later, remains well, no vomiting or headache, more than 2 years

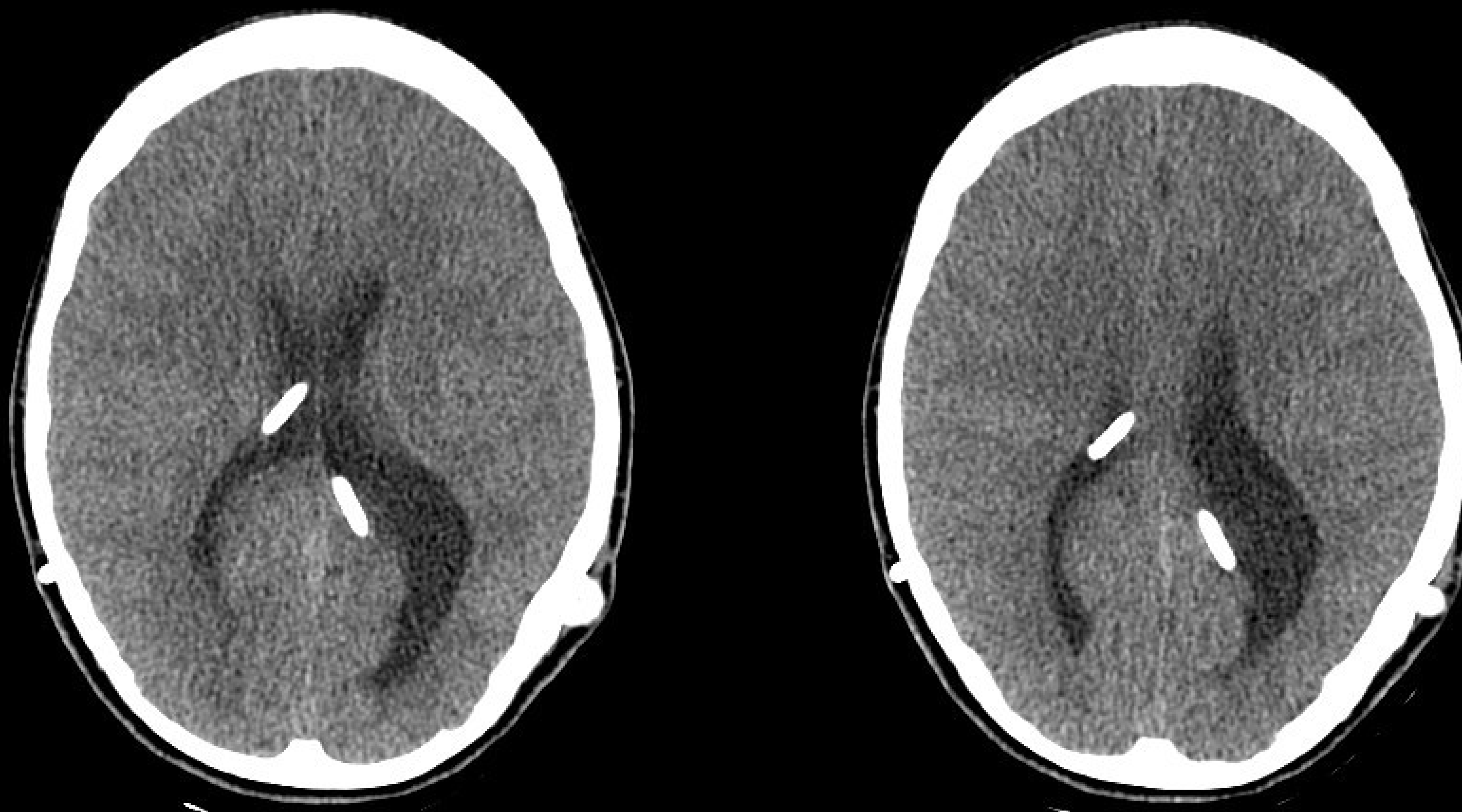


Case Example

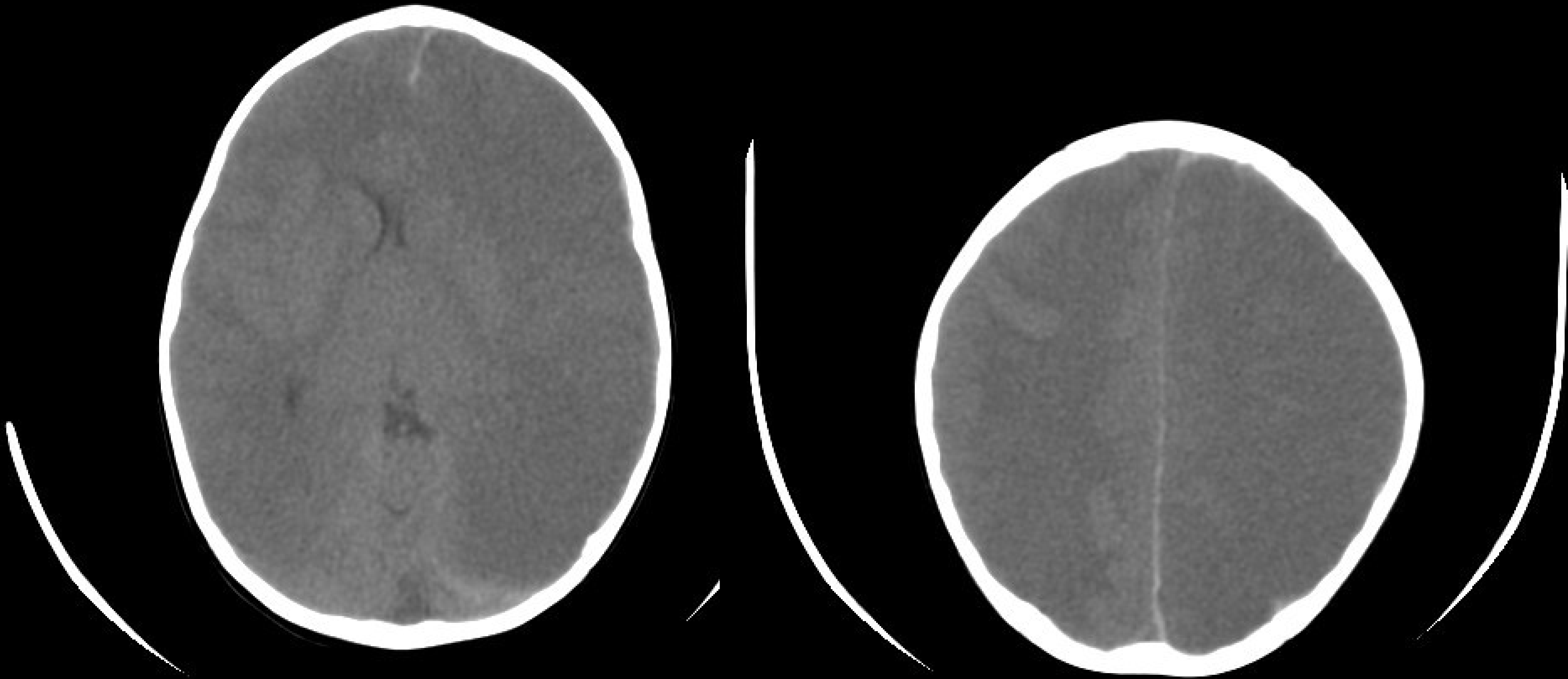
- 10 year old girl
- Severe headache "screaming"
- Bilateral shunts, multiple revisions last 3 months, small ventricles, had LP for "? meningitis", very high ICP, culture negative.
- Father crown attorney, president of local hydrocephalus association
- Patient transferred from other centre



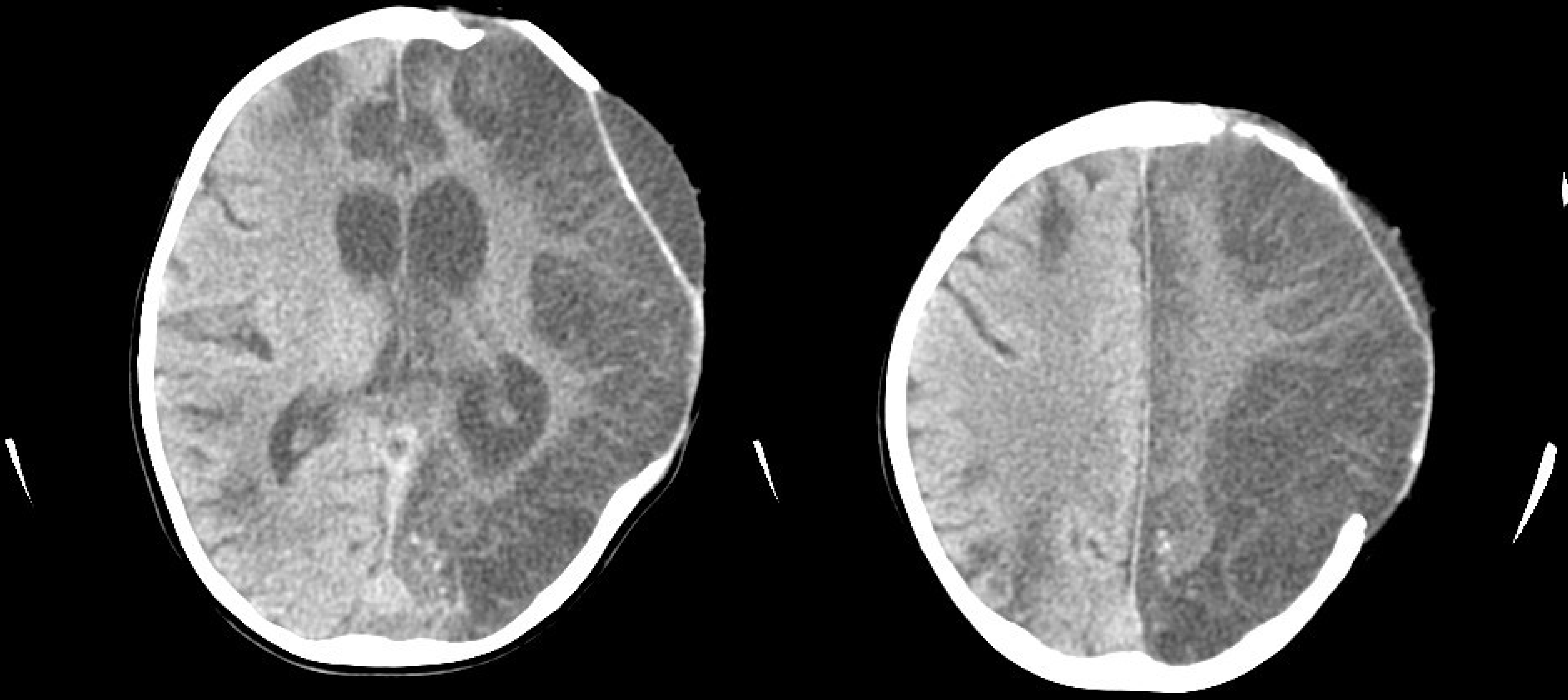
Patent shunt system, very high ICP by ventricular catheter manommetry, ventricular catheter repositioned under ultrasound, Orbis Sigma II valve, headache much improved – only 6 mos of FU!



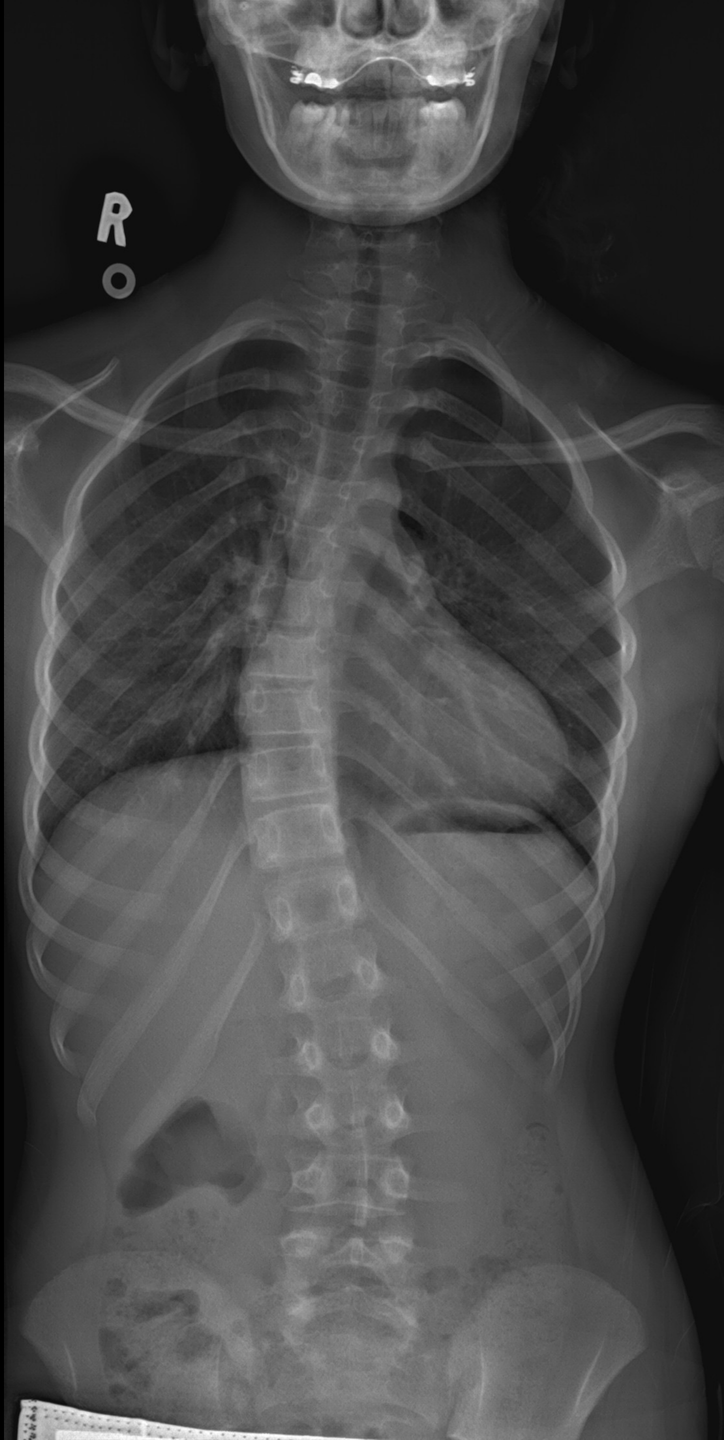
17 month girl, probable non-accidental injury

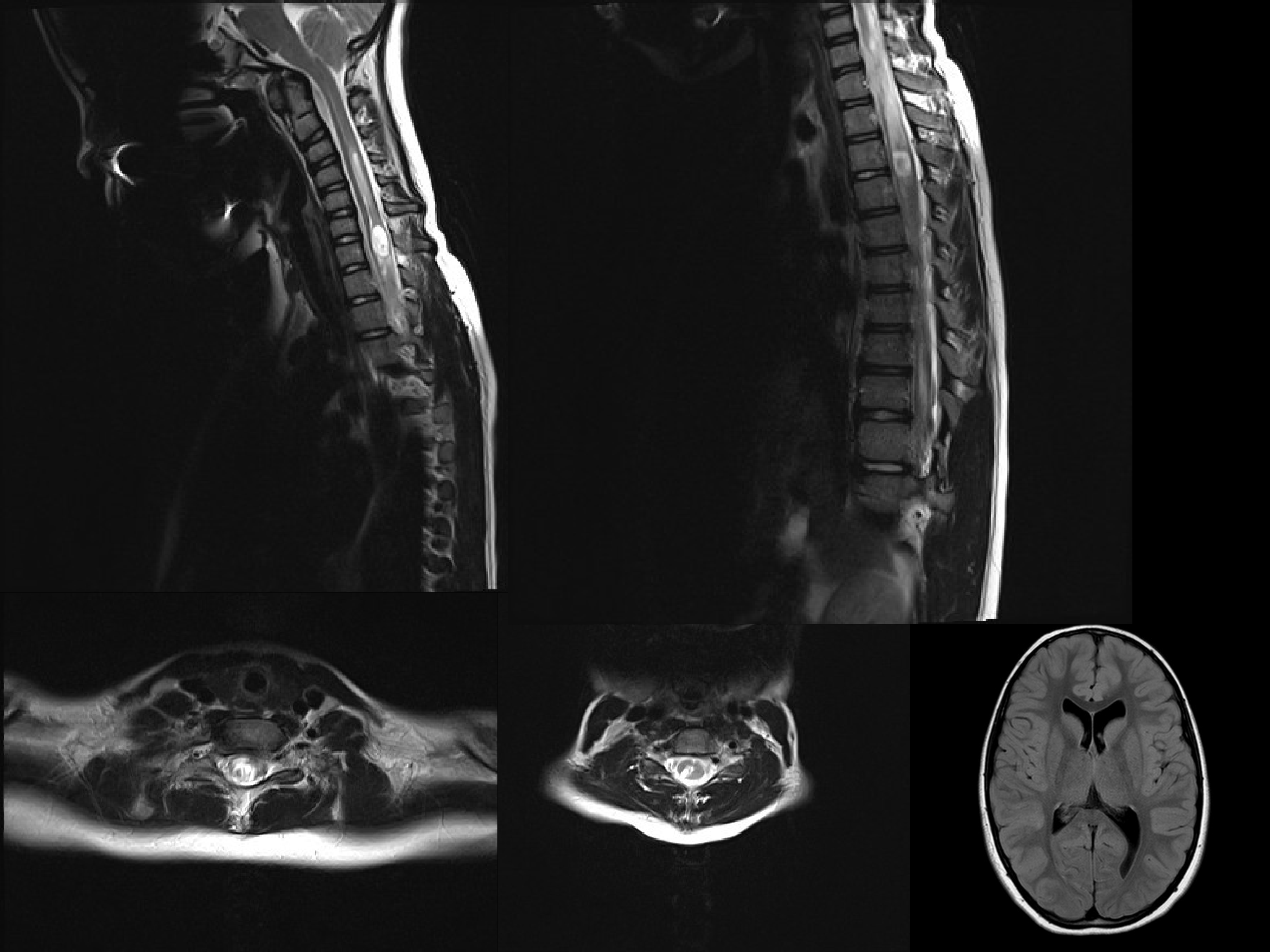


18 months later



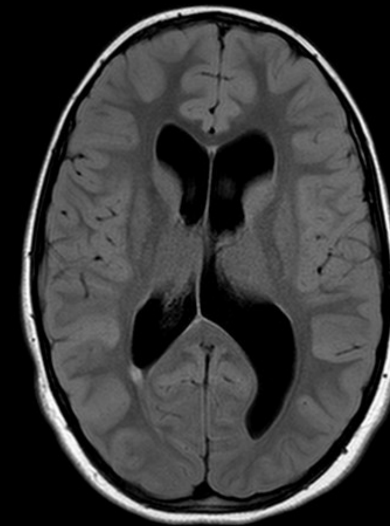
13 yr old female, arthrogryposis, scoliosis. Previous history of palatal insufficiency, mechanical.

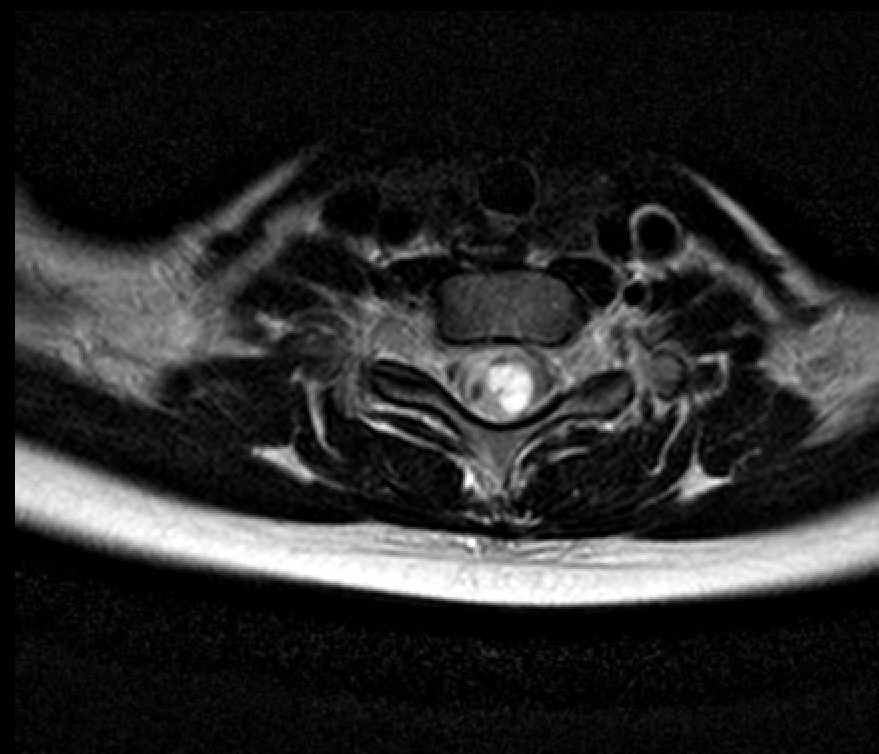




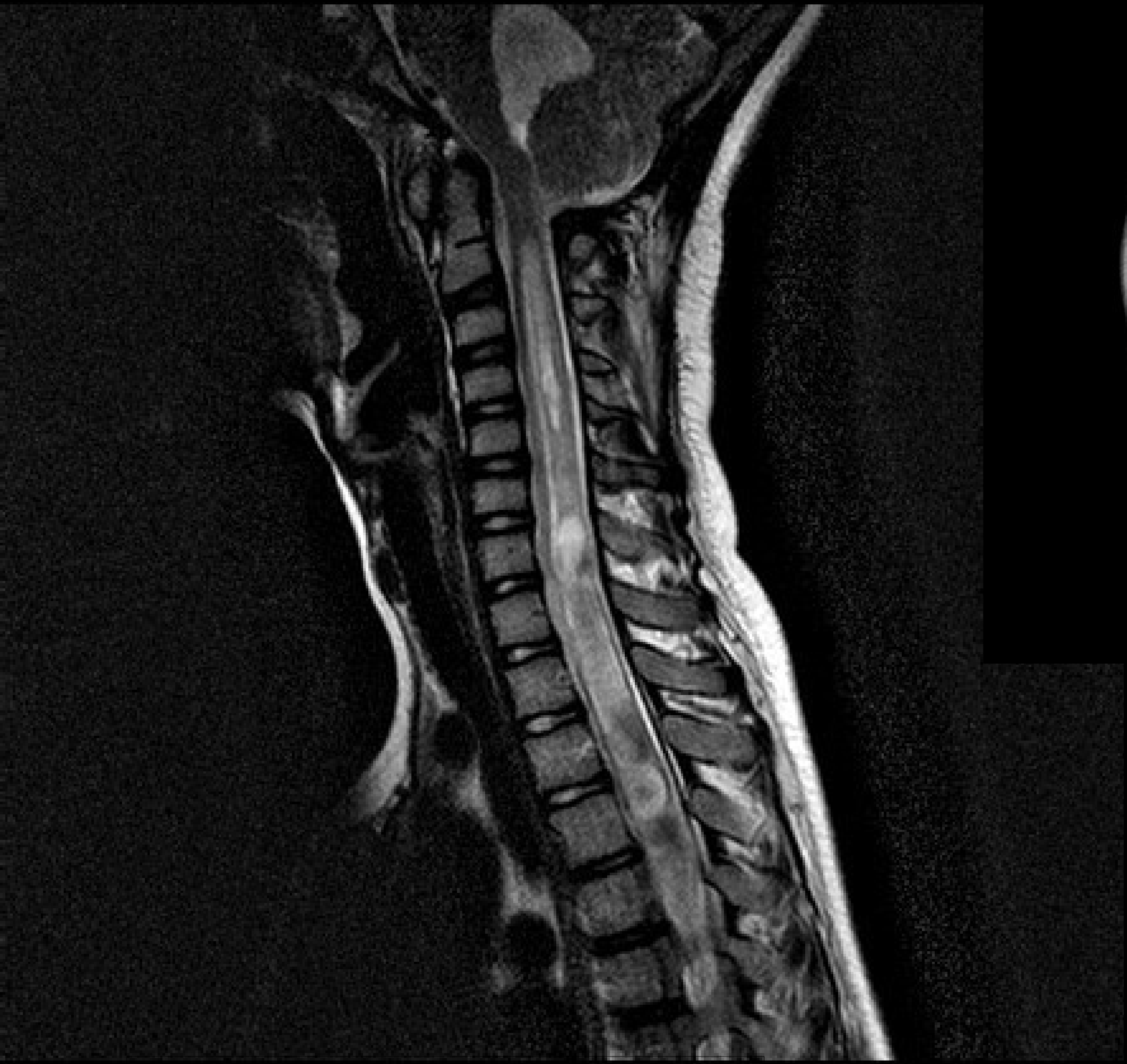
Operation

- Boney decmompression including C1
- Dural opening, cerebellar tonsils dissected under microscope, 4TH ventricle opened. Tonsils moved up, more rounded. Pericranial duraplasty.
- No immediate problems. 6 weeks post op, C/O headache. Exam normal, no papilledema.



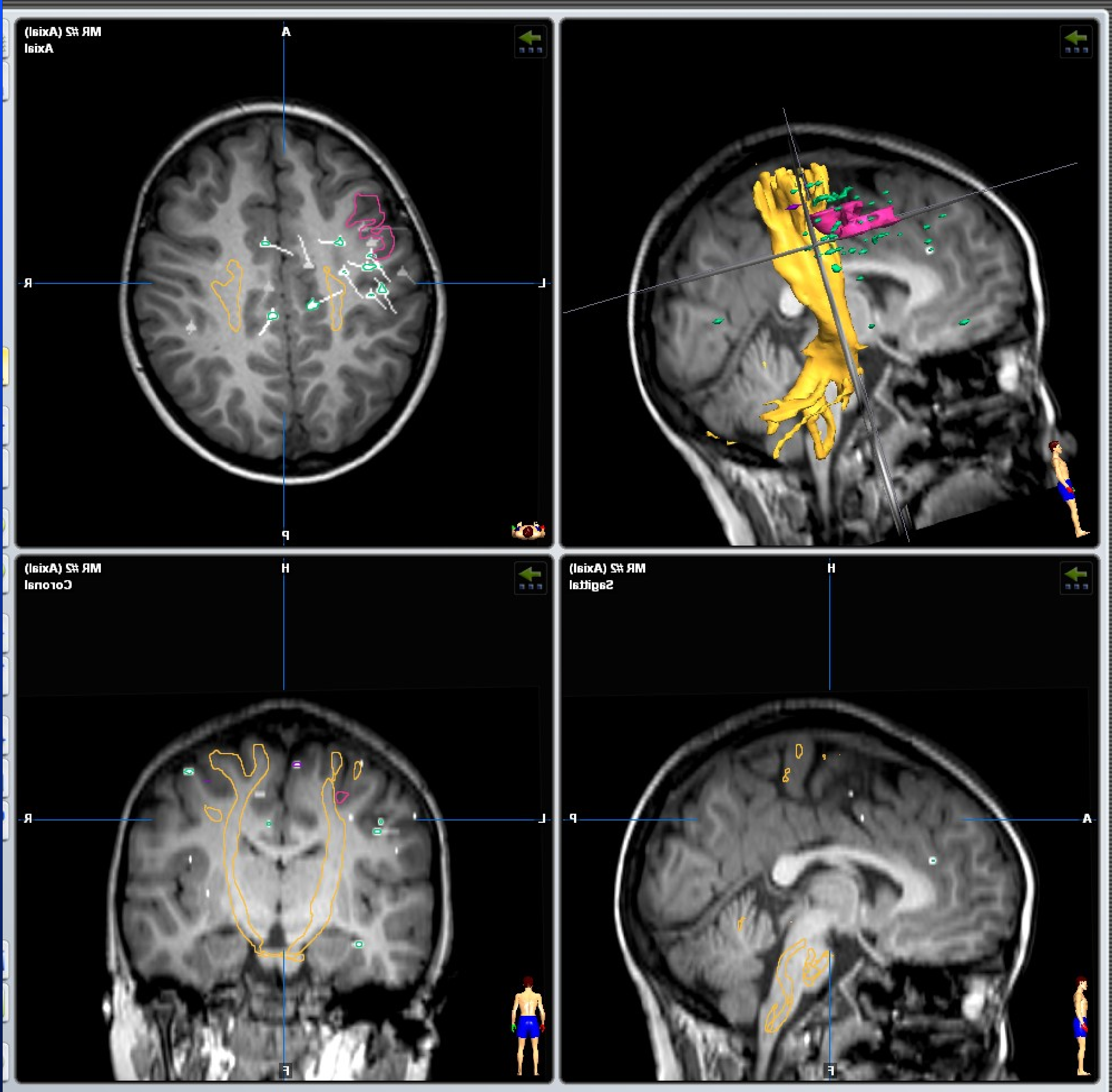


2 months post op

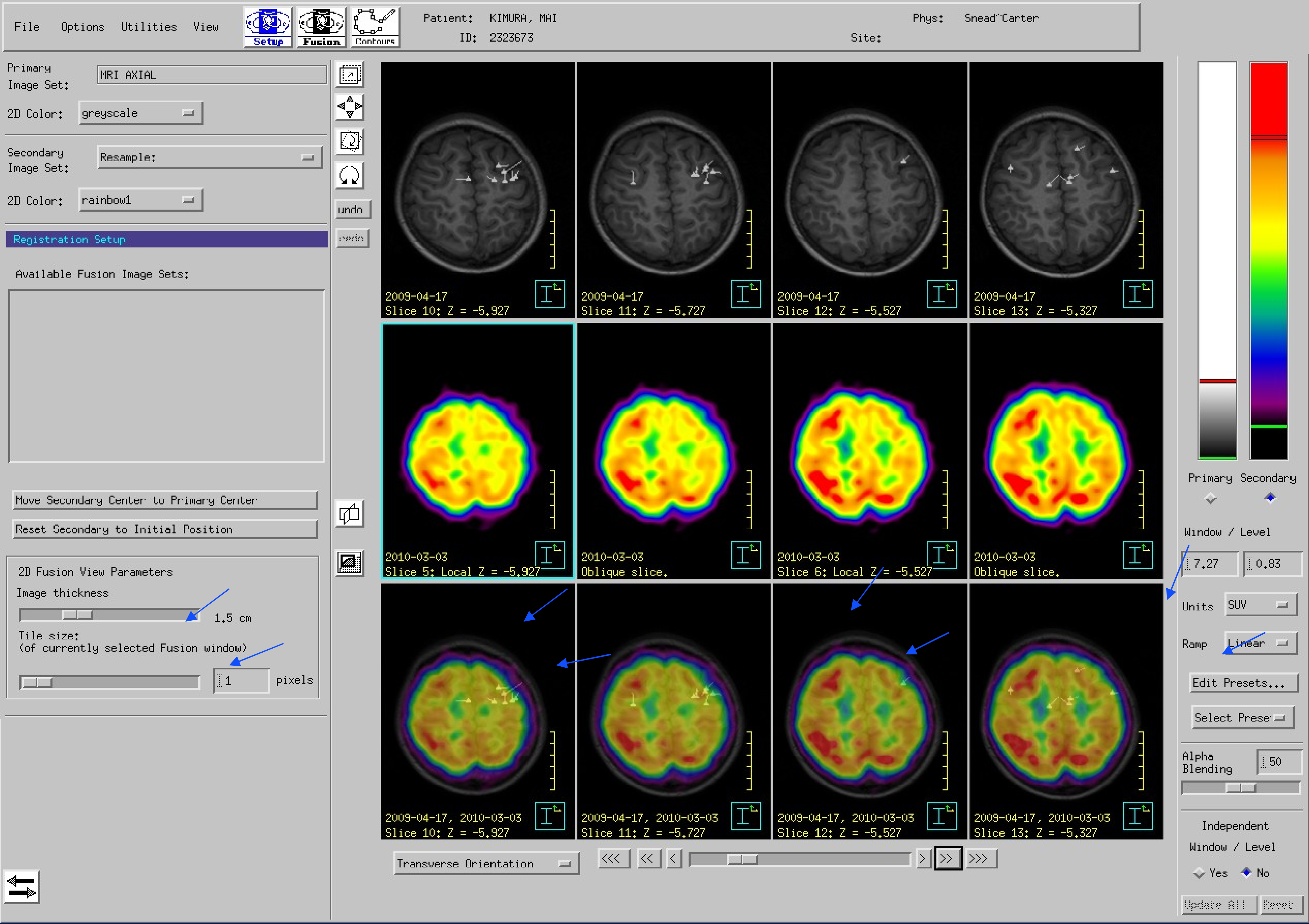


5 months post op

- Not symptomatic
- Scoliosis bit worse
- Now what ?
  - ETV
  - Shunt
  - Explore spinal “cyst”
  - Re-explore CV junction

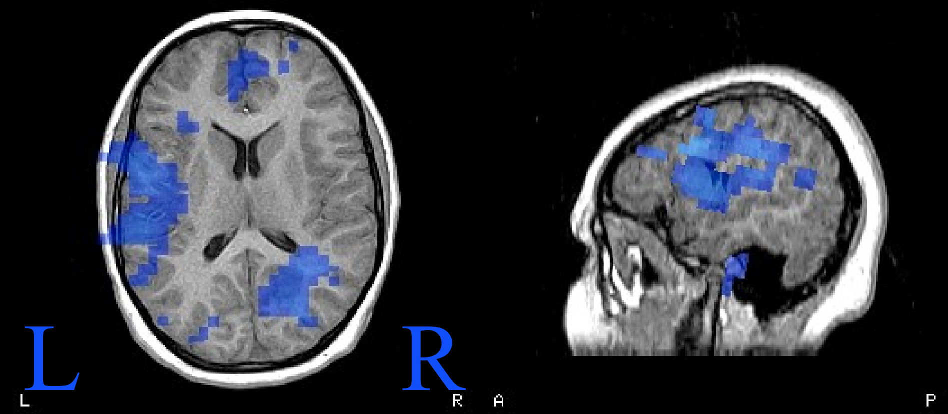


MR #2 (Axial)
Axial
A
R
L
P
MR #2 (Axial)
Coronal
H
R
L
F
MR #2 (Axial)
Sagittal
H
P
A
F

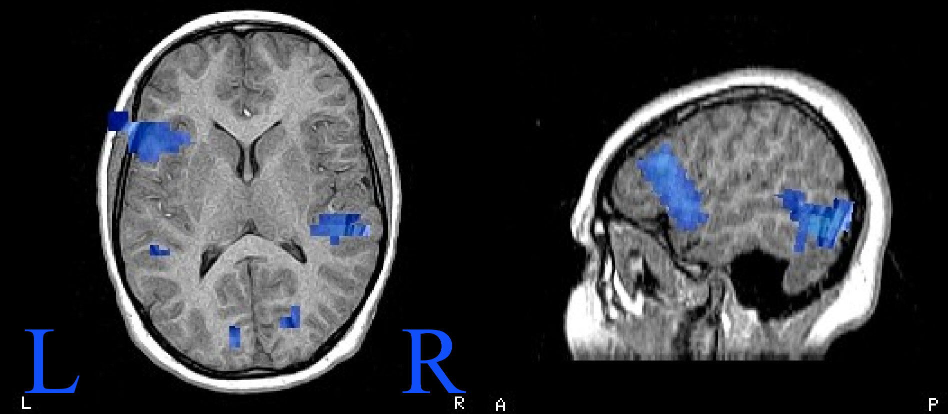

File
Options
Utilities
View
Setup
Fusion
Contours
Patient: KIMURA, MAI
ID: 2323673
Phys: Snead^Carter
Site:
Primary Image Set:
MRI AXIAL
2D Color:
greyscale
Secondary Image Set:
Resample:
2D Color:
rainbow1
Registration Setup
Available Fusion Image Sets:
Move Secondary Center to Primary Center
Reset Secondary to Initial Position
2D Fusion View Parameters
Image thickness
1.5 cm
Tile size:
(of currently selected Fusion window)
1
pixels
undo
redo
2009-04-17
Slice 10: Z = -5.927
2009-04-17
Slice 11: Z = -5.727
2009-04-17
Slice 12: Z = -5.527
2009-04-17
Slice 13: Z = -5.327
2010-03-03
Slice 5: Local Z = -5.927
2010-03-03
Oblique slice.
2010-03-03
Slice 6: Local Z = -5.527
2010-03-03
Oblique slice.
2009-04-17, 2010-03-03
Slice 10: Z = -5.927
2009-04-17, 2010-03-03
Slice 11: Z = -5.727
2009-04-17, 2010-03-03
Slice 12: Z = -5.527
2009-04-17, 2010-03-03
Slice 13: Z = -5.327
Transverse Orientation
Primary
Secondary
Window / Level
7.27
0.83
Units
SUV
Ramp
Linear
Edit Presets...
Select Prese
Alpha Blending
50
Independent Window / Level
Yes
No
Update All
Reset

TASK: MEG expressive language task to picture naming and picture verb generation

-picture naming task
-left hemisphere frontal and temporal activation



-picture verb generation
-left hemisphere frontal activation



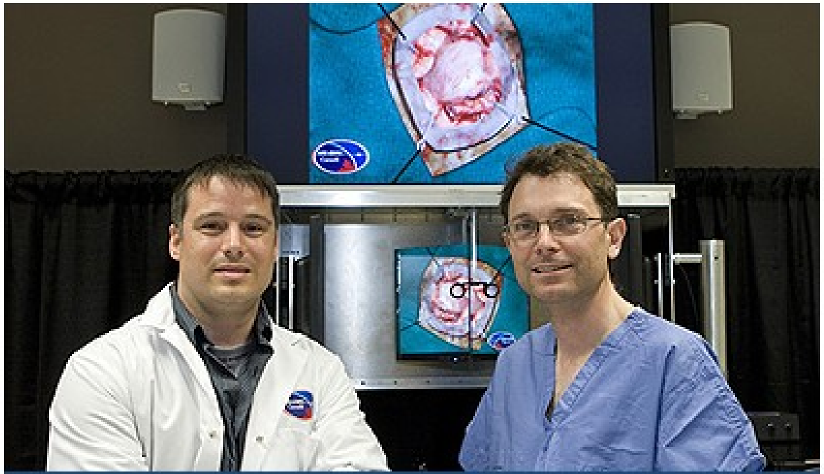
Flight Simulator

Neur

Dimensions

Surgeons practice on virtual brain

A high-tech simulator lets brain surgeons "practice" on virtual versions of their patients before the real surgery.



Dr. Ryan D'Arcy (left) and Dr. David Clarke pose in front of the neurosurgical simulator developed by NRC.

Brain surgeons around the world are abuzz over a unique virtual-reality neurological simulator, called NeuroTouch.

NeuroTouch was officially introduced at the XIV World Conference of Neurological Surgery held in Boston in late summer 2009. Developed by NRC, the groundbreaking technology enables brain surgeons to rehearse a delicate

RELATED

NRC Corporate website:

- Simulation-based brain surgery in Halifax yields breakthrough in surgical training and rehearsal

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