Shunt Device Selection

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Shunts – Standard treatment for hydrocephalus

Fig. 4. Ventriculo-peritoneal (VP) Shunt

Fig. 8. Shunt Components
To shunt or not to shunt?
Shunt Complications

• "The history of evolution of ventricular shunting is largely a history to prevent the complications of shunting." R. MacLaurin
• "The best shunt is no shunt."
• "Once a shunt, always a shunt."
Shunt materials

- Silicone rubber
- Stainless steel
- Synthetic corundum
- Plastics
- Tantalum
- Barium sulfate
Shunt valve mechanics

- Pressure regulation
- Flow regulation
- Add-on
  - Gravity compensating devices
  - External Opening Pressure adjustability
Shunt Types

1. Fixed Resistance Valve
2. Fixed Resistance Valve + Anti-siphon Device (ASD)
3. Self-Adjusting Variable Resistance Valve
4. Programmable Valve
Fixed Resistance Valves

1. Silicone Membrane
2. Ball-Spring Mechanism (Non-Silicone)
The aim is to maintain a constant pressure whatever the drainage flow rate might be.
The aim is to maintain a constant pressure whatever the drainage flow rate might be.
Pressure regulation – mechanisms

- Ball in cone
- Diaphragm
- Duck bill
- Slit

ON – OFF mechanism
Pressure regulation – mechanisms

- Ball in cone
- Diaphragm
- Duck bill
- Slit

ON – OFF mechanism

Closed
Pressure regulation – mechanisms

- Ball in cone
- Diaphragm
- Duck bill
- Slit

ON – OFF mechanism

Closed
Open
Pressure regulation – « in real life »

Imperfections
- Ramp
- « elbow »
- Hysteresis
Ball-Spring Mechanism Type
(Codman-Hakim Precision Pressure Valve)

Pressure Flow Pattern of Ball-Spring vs Silicone

\[
P = Q \times R \\
R = \frac{K \times L}{A}
\]

- \(P\) = pressure
- \(Q\) = flow
- \(R\) = resistance
- \(K\) = viscosity
- \(L\) = length
- \(A\) = area
ALL FIXED RESISTANCE VALVES SUFFER FROM SIPHONING

Hydrodynamics of a shunted patient with differential pressure (DP) or variable resistance valve

Intraventricular pressure (IVP)

Supine position

Erect position causes augmented drop in IVP

Distal hydrostatic pressure: negative pressure in erect position

Hydrostatic pressure: no negative pressure in supine position

Intraventricular pressure
A higher opening pressure DOES NOT PREVENT SIPHONING

Only sets the final negative pressure LESS NEGATIVE
Anti-siphon Devices (ASD) or Gravity Compensating Devices
Antisiphon Device (ASD)

Normally Open

Closed; Response to Distal Catheter
Negative Hydrostatic Pressure

ASD opens

ASD closes
ASD/Gravity compensating devices

• Siphon-resistive devices
  – Lying position
  – Standing
Gravity compensating devices

- “Counterweigh” the hydrostatic pressure
Flow regulated valves
Flow Regulated Valves

- Orbis-Sigma
- Delta Siphon-Control Valve
- Diamond valve
- Resistance increases as hydrostatic (siphoning) pressure becomes more negative
- Self-Adjusting Variable Resistance valves
Flow regulation – mechanism

Closed

Variable resistance

Open
Flow regulation – mechanism

Closed

Variable resistance

Open
Flow regulation – mechanism

Closed

Variable resistance

Open
Flow regulation – mechanism

Closed
Variable resistance
Open
Flow regulation – « ideal curve»

Pressure

Flow

The aim is to maintain a constant drainage flow rate for a large range of pressure variations
The aim is to maintain a constant drainage flow rate for a large range of pressure variations.
Flow regulation – « in real life »

Imperfections
- Ramp
- « knee »
- Hysteresis
Programmable valves - Externally adjustable opening pressure

- Utilizes a magnetic rotor to non-invasively set the valve opening pressure
Externally adjustable opening pressure

- Utilizes a magnetic rotor to non-invasively set the valve opening pressure
Externally adjustable opening pressure

- Utilizes a magnetic rotor to non-invasively set the valve opening pressure
Varying the opening pressure

Flow

20 ml/h

Time
Varying the opening pressure

Flow

20 ml/h

Time
How shunts work

• Fluid dynamics of shunt
  – Pressure
  – Flow = \( \frac{\text{Differential pressure}}{\text{Resistance}} \)
  – Resistance = \( \frac{(\text{length} \times \text{viscosity})}{\text{radius}^4} \)
  – Viscosity (resistance that fluid offers to shear forces)
    • 20°C to 37°C decreased by 30%
How shunts work

• Fluid dynamics of patients
  – Pressure (widely variable)
    • Position  \[\text{Ventricular Pressure} = \text{Opening pressure} - \text{Hydrostatic pressure} - \text{Drainage cavity pressure}\]
    • Vasogenic activity
  – Compliance
Pressure regulation

Pressure

Flow regulation

Flow
How these concepts compare in real life

Flow

20 ml/h

Time
How these concepts compare in real life

Flow

Pressure regulation
“draining in spurts”

20 ml/h

Time
How these concepts compare in real life

Flow

Pressure regulation
“draining in spurts”

Flow regulation

20 ml/h

Time
How does one match Shunt Parameters with Different Hydrocephalic Patients?
Brain Compliance

In an Elastic-Hollow Sphere:
Pressure (P) is related to wall Tension (T):

\[ P \propto \frac{2T}{R} \]

P varies depending on how T varies with R

\[ \frac{dP}{dR} \propto \left[ \frac{1}{R} \left( \frac{dT}{dR} - \frac{T}{R} \right) \right] \]

Thus, (dP/dR) may increase with R (positive), remain constant (equal to 0), or decrease with R (negative), depending on whether, respectively, (dT/dR) is greater than, equal to, or less than (T/R).

Thus pressure varies with volume depending on how wall tension changes with volume
Compliance

Pressure

Volume

0
Compliance

Pressure

0

Volume
Compliance

Pressure

Volume
Compliance

Pressure

Volume

0
Complex Relationship Between Tension and Volume

Thus wall tension may increase steeply, minimally, or decrease with volume expansion depending on how the wall material stretches (compliance).
The Brain Obeys the Same Basic Physical Laws but the Mathematics is More Complex

- The brain is not a perfect sphere
- The brain is not thin-walled but has varying mantle thicknesses
- The brain is surrounded by an uneven skull surface
Depending on Biomechanical Property of the Brain, Ventricular Distention May Result in:

• High Pressure in a Low Compliance System
• Medium Pressure in a “Normal” Compliance System
• Low Pressure in a High Compliance System
Brain Compliance

\[ PVI = \frac{\Delta V}{\log_{10} \left( \frac{P_p}{P_s} \right)} \]

- \( P_p \) = Peak IVP
- \( P_s \) = Stable (baseline) IVP
- \( \Delta V \) = vol. of fluid injected into ventricles

PVI = Volume of fluid necessary to raise IVP by 10 times

PVI Normogram
PVI \( \propto \) Head Circumference
PVI \( \propto \) Spinal Column Length
If the Aims of Shunting Are:

- Normalize and maintain normal ICP
- Decompress ventricles
- Avoid producing “slit ventricles”

<table>
<thead>
<tr>
<th>BRAIN</th>
<th>SHUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Compliance (LPHS, Newborns)</td>
<td>Low R</td>
</tr>
<tr>
<td>Normal Compliance (acute deteriorators)</td>
<td>Low or Medium R Medium OP</td>
</tr>
<tr>
<td>Low Compliance (“Slit ventricles”)</td>
<td>Any R High OP</td>
</tr>
<tr>
<td>Unknown Compliance (NPH, Macrocephalic child)</td>
<td>Programmable OP Low R</td>
</tr>
<tr>
<td>PT Susceptible to SDH or “Overdrainage” (NPH; CCD)</td>
<td>Self-Adjusting Vari-Resistance</td>
</tr>
</tbody>
</table>
High Compliance

Low R, Mod. Low OP (Hakim Precision Pressure = 70mm)
Normal Compliance

Low R, Medium OP (Hakim Precision Pressure = 95mm)
Low Compliance

Low R, High OP (Hakim Precision Pressure = 125mm)
Unknown Compliance
(Susceptible to SDH, LPHS)

Low R, Programmable OP (Hakim Medos starting Pressure = 130mm)

Cranio-cerebral Disproportion  Macrocephaly  Programmable Medos
Avoid Ultra-Low Pressure Valve for Newborns

Premie-IVH. Mod-High Compliance Brain

Future Low Compliance Brain
Does Matching Valve Species and Brain Compliance Really Matter?

Randomized Trial of Paediatric CSF Valve Designs

No statistical difference between valve species
## Secondary outcomes: type of endpoint

<table>
<thead>
<tr>
<th></th>
<th>Delta (115)</th>
<th>Standard (114)</th>
<th>Sigma (115)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obstruction</td>
<td>38</td>
<td>39</td>
<td>31</td>
</tr>
<tr>
<td>Overdrainage</td>
<td>9</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Loculation</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Infection</td>
<td>9</td>
<td>7</td>
<td>12</td>
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</table>

\[ P = 0.023 \]
Secondary outcomes: location of obstruction

<table>
<thead>
<tr>
<th></th>
<th>Delta (115)</th>
<th>Standard (114)</th>
<th>Sigma (115)</th>
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</thead>
<tbody>
<tr>
<td>ventr. catheter</td>
<td>16</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>valve</td>
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<td>5</td>
<td>8</td>
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<tr>
<td>distal catheter</td>
<td>7</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>fracture</td>
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<td>7</td>
<td>7</td>
</tr>
<tr>
<td>unknown</td>
<td>10</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

\[ P = 0.017 \]
Will a more expensive shunt survive longer?
Comparison of 1-year outcomes for the Chhabra and Codman-Hakim Micro Precision shunt systems in Uganda: a prospective study in 195 children

Benjamin C. Ware, M.D.

CURE Children’s Hospital of Uganda, Mbale, Uganda, East Africa

Object. The author investigated the 1-year outcomes for shunt treatment of hydrocephalic children in Uganda, comparing the results using the inexpensive Chhabra shunt ($35 US dollars), widely used in East Africa, with those using the Codman-Hakim Micro Precision Valve shunt ($650).

Methods. The results in 195 consecutive children (mostly infants) in whom shunts were placed were studied prospectively. In Group 1, 90 patients randomly received either the Chhabra or Codman shunt as primary treatment for hydrocephalus. In Group 2, 105 patients received the Chhabra shunt when endoscopic third ventriculostomy could not be performed or had failed. The end points of the study were shunt malfunction, shunt migration, wound complication, death,
In the real world, ANY SHUNT can be used in ANY HYDROCEPHALALIC STATE, and 80-90% will end up working!

WHY?

BECAUSE:
1. Most Ventricular/Brain systems adjust to the shunt given.
2. Shunt Failure is usually due to Ventricular Catheter Occlusion, and NOT to mismatched valve.
Several points to be borne in mind...

• The in-vivo performances of shunts can be quite different to that in the laboratory

• DP variations applied to the shunt in real life always exceed any opening pressure category – the brain adjusts to any implanted shunt system

• Shunt technology is not just driven by science or cost

• The surgeon is the end “manufacturer” of the shunt