Principles of shunt testing in vivo

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Shunt helps to control hydrocephalus not to cure it

DISCLOSURE: Short-term R&D agreements with various shunt manufacturers (Codman, Medtronic, Sophysa, Miethke, Cordis, Spiegelberg, etc) for shunt evaluation in Cambridge Lab.
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16. Hydrocephalus shunts
Shunt technology

• Closing mechanism: Ball on spring versus silicone membrane or mitre valves
• Programmable valves
• Preventing overdrainage
Cambridge Shunt Evaluation Laboratory
Membrane valves:
Ball on spring valves

STANDARD VALVE

PEDiatric VALVE

Inlet tubing
Ruby ball
Spring
Outlet valve
Outlet tubing
Valve housing
‘Autoregulation’ valve- OrbisSigma

- stabilizes flow, not a pressure
- prevents overdrainage
- contraindicated in patients suffering from intermittent (vasogenic) ICP waves
Codman-Medos Programmable Valve

- 18 precise steps of programming
- low resistance
- may overdrain
- may be reprogrammed accidentally
- small particles may damage opening-closing properties
Strata Valve: ‘Ball-On-Spring’ adjustable valve + Delta Siphon Controlling Device
All valves work on the same principle: magnetically movable rotor changes pre-load of spring supporting ball in cone.

Sophy Valve

Schematic diagram of construction of Sophysa Polaris Valve (Figure scanned from the leaflet provided by the manufacturer). 1: inlet connector, 2: semicircular spring; 3 & 12: radiopaque setting identification points, 4: rotor, 5: ruby axis, 6: micromagnet, 7: outlet, 8: fixation holes, 9: ruby ball, 10: adjustment lugs, 11: safety stop.
ProGAV: The unit consists of two parts: programmable ball-on-spring valve (A,B) and shunt-assistant which increases opening pressure in vertical position to prevent overdrainage (C). Programming is achieved by turning of the rotor, which controls pre-load of cantilevered spring (E). Possible adjustment is continuous from 0 to 20 cm of water.
The valve may be programmed and it’s performance level may be verified with very simple hand tools.
Hayer-Shulte Anti-Siphon Device
Siphon prevention

ShuntAssistant

C
Programmable Shunt Assistant: ProSA

Schematic diagram of construction of proSA (Figure copied from the Manufacturer web-page). 1-inlet connector, 2-outlet connector; 3- sapphire ball, 4- weight, 5- bow spring 6-rotor with micro magnets, 7- outlet,
Two channels: middle-low resistance and spiral outer- high resistance – around 40 mmHg/(ml/min). Switching may be unreliable.
Cambridge Shunt Lab 1993-2013:

Founded and maintained 1993-1997 by Department of Health, MDA, UK
Reports:

- PS Medical Delta Valve (MDA/95/42) -1, 2
- Codman Medos Programmable (MDA/95/51)
- Sophy Programmable Valve (MDA/95/55)
- Cordis Orbis Sigma Valve (MDA/95/78)
- Heyer Schulte In-Line Valve (MDA/95/74)
- Medtronic PS Medical CSF Lumboperitoneal Shunt (MDA/96/22)
- Heyer-Schule Low Profile Valve (MDA/96/39)
- Codman Hakim Precision Valve (MDA/96/59)
- Medtronic PS Medical Flow Control Valve (MDA/96/78)
- Heyer Schulte Pudenz-Flushing Valve with and without ASD (MDA/97/01)
- Codman Uni-Shunt MDA 97/42
- Review of Ten Shunts MDA 97/39
- Elekta-Cordis Omni-Shunt MDA 97/62
- Codman Accu-Flo MDA 97/67
- Radionix Contour Flex MDA 98/37
- Codman Holter Valve MDA 98/48
- Cordis Hakim Valve –1998
- Strata Valve 2001
- SinuShunt 2003
- DSV and PaediGAV Miethke Valves 2003
- Hakim Programmable with Siphon Guard 2004
- Strata NSC Valve 2005
- Miethke ProGAV Valve 2006
- Sophysa Polaris Valve 2007
- ProSA shunt assistant 2009
- Codman Certas 2011
Scattering of the pressure-flow curves

Pressure-flow curves depend on operational pressure of the valve

Valve may generate pressure waves
Influence of the peritoneal drain

Programming of the valve has been checked both using pressure-flow and flow-pressure tests. Good agreement of the pressure-flow curves with the nominal data has been recorded. The following graphs illustrate flow-pressure curves of the valve set at different performance levels.

Valve has five distinct operating performance levels.

Closing pressure values and 95% confidence limits are presented in graphical form below.
Magnetic field interactions in adjustable hydrocephalus shunts

Laboratory investigation

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Object. Exposing patients with ventricular shunts to magnetic fields and MR imaging procedures poses a significant risk of unintentional changes in shunt settings. Shunt valves can also generate considerable imaging artifacts. The purpose of this study was to determine the magnetic field safety and MR imaging compatibility of 5 adjustable models of hydrocephalus shunts.

Methods. The Codman Hakim (regular and with SiphonGuard), Miethke ProGAV, Medtronic Strata, Sophysa Sophy and Polaris programmable valves were tested in a low-intensity magnetic field, and then translational attraction (TA), magnetic torque (MT), and volume of artifacts on T1-weighted spin echo (SE) and gradient echo (GE) pulse sequences in a 3-T MR imaging unit were measured.
All programmable valves are sensitive to external magnetic field (> 10 mT)
Distortion of Gradient-Echo image:
After shunting model of CSF circulation changes

1. How pulsations of ICP influence drainage through the shunt?
2. How shunt influences pulse pressure of ICP?
It is possible thanks to parameters measured in Shunt Lab.
Testing for underdrainage

ICP < R*I_{inf} + P_{operative} + 5

Shunt works ok

Shunt underdrains

Shunt tested as ‘blocked’ distally. Too high resistance to outflow, prominent vasogenic waves. During the revision broken distal drain (at chest) was found.
Blocked ventricular catheter

Flat pressure trend
Before infusion

No detection of pulse rate or any pulse amplitude

Fast rise of pressure up to the level of distal shunt opening and fast decrease after end of infusion
Occlusion manoeuvre

Thanks to DR.A.Lavinio
Compression of SCD with ventricular end blocked (double)
Slit ventricles – pressure – initially no pulsations

ICP = 8

Thanks to DR.A.Lavinio
When ventricles re-open, pressure pulsations appear

ICP = 37

Thanks to DR.A.Lavinio
Re-opening of collapsed ventricles during distal occlusion

Infusion, no pulse

occlusion

Re-opening of ventricles
Choroid plexus in-growing int ventricular catheter

Possibly fluent CSF flow at baseline, aspiration possible, ICP pulsation visible

After start of infusion in-growing plexi jam dynamically ventricular catheter, all infused fluid flows distally, pressure pulsations disappear
Partially blocked ventricular end by in-growing choroid plexi – ICP waveform diminishes after start of infusion
Testing for overdrainage:

Most valves have non-physiologically low resistance (from 1.5 to 3mmHg/ml/min), the use of long catheter can increase this resistance by 100 – 200%.

Risk of overdrainage!

Thanks to Prof JD Pickard for illustration
Overdrainage testing - tilt test

No shunt

With overdrunning shunt
Overdrainage in long-term monitoring: long tubing + low hydrodynamic resistance of the valve
Overdrainage related to vasomotion: Increase in SLOW waves in ICP associates with decreases in recorded mean ICP
Overdrainage related to excessive pumping of prechamber:
Who needs a revision?

He does not!

He needs

She needs!!!!!

She also needs a revision!!!!

[Graphs showing ICP and AMP with marked periods and annotations like "Infusion period", "Infusion study", and "Distal blockage"]
Message to take home

• Overdrainage, underdrainage, blockage may be tested safely
• In most shunts infusion test may be done through prechanber
• Sterile technique: infection risk < 1%
• With infusion test we can avoid 30-50 unnecessary revisions a year