17. Shunt testing in-vivo
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?
Before shunting: Normal ICP, fast rising during infusion (infusion interrupted at 40 mm Hg, estimated Rcsf > 20 mm Hg/ml/min), lot of vasogenic waves, big amplitude to CSF outflow (4 mm Hg).

After shunting (Strata @ 1). Normal ICP, low rise in pressure during the test, calculated Rcsf 4 mm Hg/ml/min). Low amplitude of pulse waves (1 mm Hg) and low level of slow vasogenic waves.
Resistance to CSF outflow, pulse amplitude, baseline ICP, RAP and magnitude of slow ICP waves, all decrease after shunting.
Shunt testing in-vivo

- Underdrainage
- Blockage
- Overdrainage
Shunt testing in vivo

Laboratory model

Shunt testing in-vivo:

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

Shunt works ok

Shunt underdrains

Shunt draining properly

Graph showing ICP, AMP, and RAP over time with OCCLUSION marked.
Shunt underdraining
Overdrainage related to body posture
Statistics: 50 patients without shunt and 50 with shunts
Fast and slow phase of decrease in ICP in sitting position

No shunt

With shunt
Overdrainage in long-term monitoring: long tubing + low hydrodynamic resistance of the valve
Laboratory study on "intracranial hypotension" created by pumping the chamber of a hydrocephalus shunt
Adam Bromby, Zofia Czosnyka, David Allin, Hugh K Richards, John D Pickard and Marek Czosnyka*
‘HEMODYNAMIC’ CONSEQUENCES OF SIPHONING

When ICP > Pss, ICP and Pv are coupled; therefore gradient Pv-ICP is low (<5mm Hg)

When ICP falls below Pss, Pv-ICP coupling disappears

Therefore, gradient Pv-ICP may increase to very high values (coughing, bodily exercises) causing bleeding
Blockage of ventricular catheter
Occlusion manoeuvre

Thanks to DR. A. Lavinio
Compression of SCD with ventricular end blocked (double)
Collapsed ventricles: in case of shunt with membrane SCD

Patency of ventricular catheter

To pressure transducer

To infusion syringe

Thanks to DR.A.Lavinio
Performance of valve / distal catheter

Thanks to DR.A.Lavinio
Occlusion manoeuvres

Thanks to DR. A. Lavinio
Occlusion manoeuvres

Thanks to DR.A.Lavinio
Thanks to DR. A. Lavinio
ICP = 37

Thanks to DR.A.Lavinio
Re-opening of collapsed ventricles during occlusion test
‘Isolated’ shunt prechamber

Aqueduct stenosis. Last revision Dec 2004: Strata @ 1.5 ?
Infusion via shunt prechamber, under sedation.

▼▼▼ infusion started and stopped 3 times

It was not possible to aspirate the fluid -> needles flushed prior to insertion.
There was no pulse waveform in the pressure signal.
In response to infusion (3 attempts) the pressure in the prechamber increased rapidly to high values. This suggests that the shunt prechamber is isolated => both shunt ends blocked.
INTERACTION BETWEEN CSF DRAINAGE THROUGH HYDROCEPHALUS SHUNT AND PRESSURE WAVES
Shunt testing rig. $P$ and $P_{\text{past}}$ were measured when pulse generator amplitude was varied throughout the experiment.
When valve opens, $P_{\text{past}}$ increases, indicating increase in flow rate through the valve. During this periods outflow resistance is lower (valve is opened $R=R_{\text{csf}} \parallel R_{\text{shunt}}$) than in periods when shunt is closed ($R=R_{\text{csf}}$). As a result peaks of $P$ increase slower than valleys decrease. Operating pressure decreases.
Does it matter in clinical practice?

Example of negative mean ICP in horizontal body position in a patient who hyperventilated habitually when awake, therefore the amplitude of respiratory wave was very high (around 20 mm Hg peak-to-peak). Pressure increased when he fell asleep and started to breathe normally.
Overdrainage related to waves in CBV:
Overdrainage related to waves in CBV:
Value of Overnight Monitoring of Intracranial Pressure in Hydrocephalic Children

Martin U. Schuhmann\textsuperscript{a,c} Sandeep Sood\textsuperscript{a} James P. McAllister\textsuperscript{a,b} Matthias Jaeger\textsuperscript{d} Steven D. Ham\textsuperscript{a} Zofia Czosnyka\textsuperscript{e} Marek Czosnyka\textsuperscript{e}

\textsuperscript{a}Department of Pediatric Neurosurgery, Children’s Hospital of Michigan, Wayne State University School of Medicine, Detroit, Mich., and \textsuperscript{b}Department of Neurosurgery, Division of Pediatric Neurosurgery, Primary Children’s Medical Center, Salt Lake City, Utah, USA; \textsuperscript{c}Department of Neurosurgery, University Hospital Tübingen, Tübingen, Germany; \textsuperscript{d}Department of Neurosurgery, Liverpool Health Service, University of New South Wales, Sydney, Australia; \textsuperscript{e}Academic Neurosurgery Unit, University of Cambridge Clinical School, Cambridge, UK

Table 1. Distribution of 65 overnight recordings into 3 groups of shunt function/hydrocephalus

<table>
<thead>
<tr>
<th>Group</th>
<th>ICP\textsubscript{baseline} mm Hg</th>
<th>ICP\textsubscript{peak} mm Hg</th>
<th>RAP\textsubscript{peak}</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Functional shunt/no hydrocephalus</td>
<td>$P_0 \pm 2.5$</td>
<td>$&lt;25$</td>
<td>$&lt;0.6$</td>
<td>19</td>
<td>29</td>
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<tr>
<td>2 Questionable shunt function/possible hydrocephalus</td>
<td>$P_0 \pm 2.5$</td>
<td>$&lt;25$</td>
<td>$&gt;0.6$</td>
<td>9</td>
<td>20</td>
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<tr>
<td></td>
<td>$P_0 &gt; 2.5$</td>
<td>$&lt;25$</td>
<td>$&lt;0.6$</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3 Malfunction of shunt/active hydrocephalus</td>
<td>$P_0 &gt; 2.5$</td>
<td>$&lt;25$</td>
<td>$&gt;0.6$</td>
<td>10</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>$P_0 &gt; 2.5$</td>
<td>$&gt;25$</td>
<td>$&gt;0.6$</td>
<td>23</td>
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</table>

n = Number of recordings; % = percentage of total recordings.
Overnight monitoring of a 9-year-old boy from group 3 with shunt malfunction. Episodes of increased amplitudes of SLOW, so-called vasogenic waves, are depicted in grey. This patient was born as a full-term baby with intraventricular hemorrhage and received a shunt thereafter. His last shunt revision was 6 months previously. For several weeks, he was more irritable and droopy, although maintaining a high activity level. In the last 2 weeks before monitoring, he woke up at night and held his head, although he would not complain about pain or a headache. A week before admission, he had a short episode of lethargy and vomited twice. His CT scan on admission was unchanged and he had no papilledema. Interpretation of monitoring: the ICP baseline stabilized at 15 mm Hg, which was above the tolerance zone for a PS Medical medium-pressure valve (P o 8.2 8 2.5 mm Hg). He had 7 vasogenic wave events, already the first exhausted compensatory reserve with a RAP peak of almost 1. The following 4 major episodes were clearly uncompensated, with ICP peaks above 30 mm Hg and large increases in SLOW amplitude to 1 9 mm Hg. RAP peak in these episodes was close to 1. Finally, he had a long episode of ICP increase for almost 1 h, incorporating several consecutive pressure waves. During this time the RAP continuously indicated exhaustion of compensatory reserve. The recording showed all 3 criteria above thresholds, and thus was defined as group 3 ‘shunt dysfunction’. At surgery, the valve was found blocked and was exchanged. Postoperatively, his symptoms resolved.
Fig. 3. Overnight monitoring of a patient from group 1 with a fully functional shunt system and no compromise of intracranial reserve capacity. Episodes of increased amplitude of SLOW, so-called vasogenic waves, are depicted in grey. He was a 17-year-old boy with a ventriculoperitoneal shunt system connected to 3 proximal catheters. He had experienced a cluster of 29 shunt revisions in the last 2 years; the last revision was 4 months ago. He suffered from headaches for many years and was treated by the psychiatric team for pain control, including regular morphine medication. The slit appearance of his ventricles was unchanged and he carried a Strata valve with a $P_v$ of $4.0 \pm 2.5$ mm Hg. He was monitored to rule out underdrainage or positional overdrainage as the cause of a recent increase in headache severity. Interpretation of recording: his baseline ICP was $5.21 \pm 1.23$ mm Hg, and thus within the expected limits of the valve. Peak ICP during 4 episodes, which might represent vasogenic like events, remained below 15 mm Hg. During those episodes with increased ICP there was no increase in RAP, indicating no compromise of the cerebrospinal reserve capacity. Therefore, shunt underdrainage was ruled out as a reason for his recent complaints.
Thanks to Prof. M. Schuhmann
Fig. 5. Box plots showing the results for $ICP_{\text{baseline}}$, $ICP_{\text{wave}}$, $ICP_{\text{max}}$, $RAP_{\text{baseline}}$, $RAP_{\text{wave}}$, $AMP_{\text{baseline}}$, $AMP_{\text{wave}}$, $SLOW_{\text{baseline}}$ and $SLOW_{\text{wave}}$ for the 3 classes of shunt function. The horizontal lines inside the boxes are the medians; boxes themselves represent the interval between the 25th and 75th percentiles of the variable; small horizontal lines mark the 10th and 90th percentile; circles mark values above the 90th and below the 10th percentile. $^a p < 0.01$, $^b p < 0.02$. Thanks to Prof. M. Schuhmann.
OVERNIGHT ICP MONITORING

Summary of averaged parameters in non-shunted, shunted with not working shunt and shunted with shunt working correctly.

Those shunted with non-working shunt are equivalent to non-shunted patients with hydrocephalus.
The UK Shunt Registry

Prof. John Pickard  Registry Supervisor
Dr. Helen Seeley  Auditor
Dr. Hugh Richards  Data Manager
[Karin Christensen  Secretary]
# Shunt Registry Form

## Demographic Details

- **Patient Identification:**
  - Hospital Number
  - Hospital
- **Surname:**
  - maiden or former name
- **Forename(s):**
- **Address:**
- **Postcode:**
  - Date of Birth:
  - Sex: M/F

## Diagnosis

- **Clinical Diagnosis:**
  - Malformations
  - Acquired
  - Idiopathic
  - Other
- **Idiopathic:**
  - 'Normal pressure' hydrocephalus of the elderly
  - Benign Intracranial Hypertension

## Reasons for Revision

- **If Revision:**
  - Underdrainage: Proximal, Valves, Distal
  - Disconnection: Proximal/Valve, Valve/Distal, Other
- **Fracture:**
  - Proximal
  - Distal
- **Migration:**
  - Up
  - Down
- **Infection:**
  - Yes
  - No (Do NOT include Wound)
- **Date Revised Shunt:**
  - d d m m y y
  - Overdrainage:
    - Subdural Hygroma
    - Subdural Haematoma
    - Cranostenosis
    - Sin Ventricles
  - If revision was originally inserted

## Technical Details

- **If Shunt Removal:**
  - Replace with Extraventricular Drain
  - Shunt still functioning on removal
- **Operation Details:**
  - Date d d m m y y
  - Starting Time
  - Finish Time
  - (24 Hour Clock)
  - More than one Surgeon?
  - Consultant
- **Site of Insertion of Proximal Catheter:**
  - Right
  - Left
  - F P O Cyst
  - Lumbar
  - Other
  - Specify
- **Drainage to:**
  - Peritoneum
  - Atrium
  - Thorax
  - External
  - Other
  - Specify
- **Ventricular Catheter:**
  - Manufacturer
  - Type
  - Cat. No
  - Ser. No.
- **Distal Catheter:**
  - Manufacturer
  - Type
  - Cat. No
  - Ser. No.
- **Valve:**
  - Manufacturer
  - Type
  - Cat. No
  - Ser. No.
- **If programmable:**
  - Setting
  - Integral Reservoir
  - Separate Reservoir
- **Additions:**
  - Anti-Siphon Device
  - Other
  - Specify
  - Manufacturer

Please return to: UK Shunt Registry, Department of Neurosurgery, Box 167, Addenbrooke's Hospital, FREEPOST CB125, CAMBRIDGE CB2 2BR

Thanks to DR HK Richards
Returns  May 1995 - Dec 2009

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<td>Unknown</td>
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**TOTAL 55146**

Thanks to DR HK Richards
NPH by Centre
(% New Adult Patients 2005-2009)

Thanks to DR HK Richards
Cumulative Revision Rate (Kaplan-Meier)

- Paediatric Revisions (n=6462)
- Adult Primary (n=13206)
- Paediatric Primary (n=4902)
- Adult Revisions (n=7937)

Thanks to DR HK Richards
Revision Rate by Centre - Adults

1 Year Cumulative Revision Rate (%)

Centre

Thanks to DR HK Richards

U.K. Shunt Registry
Summary

Overdrainage, underdrainage, blockage may be tested safely.
In most shunts test infusion/measurement may be done through prechanber.
Sterile technique: infection risk < 1%
Not all early morning headaches are related to underdrainage. Overdrainage may be caused to vasocycling associated with REM phase of sleep.
Pumping of shunt prechamber- bad habit.
Shunt registry: valuable tool to monitor hydrocephalus management.