ICP overnight dynamics of pediatric patients
hydrocephalus - macrocephaly - craniostenosis

Martin U. Schuhmann, Julian Zipfel, Susanne Kerscher, Sandra F. Dias

Division of Pediatric Neurosurgery
Department of Neurosurgery
Eberhard Karls University Hospital of Tübingen
Hydrocephalus - What do we have ?
Hydrocephalus - What do we have?

more insights due to new concepts
Hydrocephalus - What do we have?

more insights due to new concepts

don’t believe in bulk flow theory (from CP to AG)
intra-ventricular obstruction AND extra-ventricular obstruction
distortion/loss of CSF pulsatility in basal cisterns leads to HC
many ways of CSF absorption - forget Paccioni granulations
venous system: important role in primary disease & overdrainage
hydrocephalus is a low compliance disease
Hydrocephalus - What do we have?

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**sexy other** means of investigation: ultrasound, telemetry, **computerized ICP analysis**
What are we missing?

transfer of new concepts into clinical practice
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majority of neurosurgeons not interested in understanding

acknowledgment of pressure compensated hydrocephalus

accept responsibility for 70-80 y of life influenced by our Tx decisions

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- compliance, pulsatility & ICP dynamics based **objective physiology criteria** for **indication** of treatment and its **success**

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- compliance, pulsatility & ICP dynamics based objective physiology criteria
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- routine quantitative assessment of shunt function - SIS

- non-invasive assessment of ICP and compliance/reserve capacity : ONSD

- US assessment of ventricles after fontanel closure
need for improvement - diagnosing compensated HC

Ventriculomegaly
Macrocephaly
S&S of raised ICP

= pressure-active

Hydrocephalus
need for improvement - diagnosing compensated HC

Ventriculomegaly
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Hydrocephalus

Ventriculomegaly ±
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no crossing head growth
no other S&S raised ICP

= compensated
Hydrocephalus
need for improvement - diagnosing compensated HC

Ventriculomegaly
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= pressure-active Hydrocephalus

Ventriculomegaly ± Macrocephaly
no crossing head growth
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= compensated Hydrocephalus

Ventriculomegaly ± macrocephaly
no crossing head growth
no S&S raised ICP

= (relative) brain atrophy
harmless ventriculomegaly?
chronic compensated hydrocephalus?
ICP analysis of nocturnal dynamics

no shunt - no reservoir - ventriculomegaly - ± macrocephaly - no obvious symptoms
ICP analysis of nocturnal dynamics

no shunt - no reservoir - ventriculomegaly - ± macrocephaly - no obvious symptoms

- ICP transducer at hairline, no shaving, short intubation/sedation
- 5 mm burrhole, screw, intraparenchymal sensor
- children run around all day, go to bed, when asleep parents connect
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}

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65 recordings in 32 children at different occasions
previous work in **symptomatic children with shunts**

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- **29%** ICP<sub>B</sub> o.k. ICP<sub>p</sub> < 25 RAP<sub>p</sub> < 0.6
- **20%** ICP<sub>B</sub> o.k. ICP<sub>p</sub> < 25 RAP<sub>p</sub> > 0.6
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previous work in symptomatic children with shunts

1) normal  
   n=19

2) borderline  
   n=13

3) pathological  
   n=33
previous work in **symptomatic children with shunts**

1) normal  
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„Functional“ group: 3 children underwent revision, shunts found functional
previous work in symptomatic children with shunts

1) normal
n=19
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"Functional" group: 3 children underwent revision, shunts found functional

"Pathological" group: all underwent shunt revision earlier or later
all shunts exchanged
ICP dynamics definition of having pressure compensated hydrocephalus
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normal or borderline baseline ICP

(normal < 10 mmHg, borderline <15 mmHg, raised > 15 mmHg)

(adult iNPH: < 17.6 mmHg baseline)
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PLUS 2 of the following
ICP dynamics definition of having pressure compensated hydrocephalus

normal or borderline baseline ICP
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(adult iNPH: < 17.6 mmHg baseline)

PLUS 2 of the following

• ↑ ICP peaks during nocturnal vasogenic episode (≥25 mmHg)
• ↑ frequency of VE (>5 in 8h)
• indices of decrease in intracranial compliance and reserve capacity
  - ↑ baseline and peak amplitude (AMP >1 and > 1.5 mmHg)
  - ↑ RAP during vasogenic episode (>0.6 )
  - ↑ ICP slow wave magnitude during vasogenic episodes (>2 mmHg)
ICP analysis of overnight dynamics

1 y old known, IVH as premature birth
ventricles too large, AS on intial HR- MRI, HC normal,
repeat MRI at 1y: AS resolved
now: ventricles still enlarged, no S&S of raised ICP
ICP analysis of overnight dynamics

ICP: 0.0 [mmHg]
AMP: 0.0 [mmHg]
Slow: 0.0 [mmHg]
RAP: 0.0 [mmHg]

Time scale: < 10 hours, 27 minutes, 45 seconds
20/05/2010 20:35:21 - 21/05/2010 07:03:06
ICP analysis of overnight dynamics

The graphs depict the intracranial pressure (ICP) and other parameters over a period of time. The data is presented in two time scales: one for a period of 10 hours and 27 minutes, and another for a period of 8 hours, 15 minutes, and 46 seconds. The graphs show fluctuations in ICP, AMP, RAP, and slow waves, which are important indicators of brain health and pressure dynamics.
ETV re-closure - shunt?

5 y old, shunt as newborn, perfect development, smart prox. cath obstructed, large vents, NO S&S at all.

MRI: Blake’s Pouch,
1) ETV, 2) Re-ETV, re-reclosure of stoma

Parents: does he need treatment (shunt revision) at all?
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9 y old boy, Noonan Syndrom, macrocephaly, ventricles normal, unchanged in last 5 years
AS on HR- MRI, old shunt in place, no capsule to pump/puncture

subtle: school performance deteriorating, need to sleep in afternoon, pressure feeling in head
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subtle: school performance deteriorating, need to sleep in afternoon, pressure feeling in head

shunt valve partially obstructed
post-op: school performance improved no afternoon sleeps, pressure feeling gone
ICP analysis of nocturnal dynamics

37 kids without HC (or with non-puncturable shunt)

Sandra F. Dias et al, manuscript in preparation
ICP analysis of nocturnal dynamics

37 kids without ? HC (or with non-puncturable shunt)

14/37 classified normal / mildly abnormal (37%):
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no difference in age
difference in Evans/FOHR

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<td>&lt;25</td>
<td>≤1</td>
<td></td>
<td>&lt;0.6</td>
<td></td>
<td></td>
<td>&lt;2</td>
<td>≤5</td>
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23/37 classified pathological (63%): all treated by shunt or (some) ETV

<table>
<thead>
<tr>
<th>ICP&lt;sub&gt;base&lt;/sub&gt;</th>
<th>ICP&lt;sub&gt;max&lt;/sub&gt;</th>
<th>ICP&lt;sub&gt;w&lt;/sub&gt;</th>
<th>AMP&lt;sub&gt;base&lt;/sub&gt;</th>
<th>AMP&lt;sub&gt;w&lt;/sub&gt;</th>
<th>RAP&lt;sub&gt;base&lt;/sub&gt;</th>
<th>RAP&lt;sub&gt;w&lt;/sub&gt;</th>
<th>Slow&lt;sub&gt;base&lt;/sub&gt;</th>
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<tr>
<td>11.6</td>
<td>30.6*</td>
<td>16.7*</td>
<td>1.19</td>
<td>2.02</td>
<td>0.43</td>
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14/37 classified normal / mildly abnormal (37%): no action taken

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<th>ICP_{base}</th>
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<th>AMP_{base}</th>
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<th>RAP_{base}</th>
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<td>21.1</td>
<td>12.3</td>
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<td>0.50</td>
<td>1.04</td>
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Group 1: 71% (10/14) showed positive development in FU

Group 2: 96% (22/23) showed positive development in FU
ICP analysis of nocturnal dynamics
ICP analysis of nocturnal dynamics

applying thresholds from symptomatic children with known hydrocephalus to a- or oligosymptomatic with questionable hydrocephalus

• 2 relatively distinct groups regarding nocturnal dynamics
• pathological group has larger ventricles
ICP analysis of nocturnal dynamics

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• decrease of reserve capacity in „pathological group“:
  - higher peak and wave ICPs, higher wave AMP and RAP
  - higher rate of nocturnal waves
ICP analysis of nocturnal dynamics

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shunted pathological group shows higher rate of positive development in FU than non-treated „normal“ group.

- treatment of pathological patterns seems to be indicated and beneficial
ICP analysis of questionable craniostenosis (CS)

secondary CS with intracranial hypertension
- 6.2% in nonsyndromic single suture synostosis
- 10-37% in syndromic synostosis
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secondary CS in non-syndromic synostosis

Sagittal (5%) > Coronal > Metopica (1.9%)
overall 6.9%
89% additional coronal synostosis after sagittal suture repair
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unspecific symptoms & signs

head x-ray: ongoing discussion
if copper beaten skull is indirect
sign of ↑ ICP or due to dysplasia

bony changes are a continuum
hard to cluster
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perfect indication for ONM of ICP

ICP-Overnight monitoring
- 25 cases in Würzburg
- 9 cases in Tübingen
ICP analysis of questionable craniostenosis (CS)

- ICP baseline 15.7 mmHg (11-26, 3.21)
- RAP baseline 0.50 (0-1, 0.13)
- AMP baseline 1.15

- $\text{ICP}_{\text{REM}}$ 20.8 mmHg (14-38, 5.12)
- maximum ICP 38.28 mmHg (19-70, 9.72)
- $\text{RAP}_{\text{REM}}$ 0.69 (0-1, 0.13)
- $\text{AMP}_{\text{REM}}$ 2.08
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non-syndromal vs. syndromal children
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non-syndromal vs. syndromal children
ICP analysis of questionable craniostenosis (CS)

- normal: 3
- mild: 10
- moderate: 9
- severe: 8

none (little)  
mild  
moderate  
severe
ICP analysis of questionable craniostenosis (CS)

none (little)  mild  moderate  severe
ICP analysis of questionable craniostenosis (CS)

No significant difference in all mean ICP (baseline, REM, peak) with very heterogeneous data distribution

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ICP analysis of questionable craniostenosis (CS)

upper breakpoint of ICP/RAP correlation: loss of autoregulation
ICP analysis of questionable craniostenosis (CS)

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ICP analysis of questionable craniostenosis (CS)

upper breakpoint of ICP/RAP correlation: loss of autoregulation

compensatory reserve is exhausted

- autoregulation fails
- loss of correlation of ICP amplitude (AMP) to mean ICP
ICP analysis of questionable craniostenosis (CS)

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upper breakpoint of ICP/RAP correlation: loss of autoregulation

compensatory reserve is exhausted
- autoregulation fails
- loss of correlation of ICP amplitude (AMP) to mean ICP

mild: no breakpoint
moderate: upper breakpoint 25.4 mmHg
severe: upper breakpoint 23.9 mmHg
Computerized ICP analysis
Computerized ICP analysis

- enables identification of pathological ICP patterns in a- & oligosymptomatic children: **signature of Hydrocephalus exists**
Computerized ICP analysis

- enables identification of pathological ICP patterns in a- & oligosymptomatic children: \textit{signature of Hydrocephalus exists}
- objective physical data help in decision making
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- chronic compensated hydrocephalus exists and is as much a LOW RESERVE CAPACITY DISEASE as pressure active hydrocephalus
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• *craniostenosis* needing re-surgery can be identified
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• in doubt go the extra mile

because our decisions influence decades of life ahead
Thank you for your attendance