Intracranial Pressure is More than a Number
CONTINUOUS RECORDING AND CONTROL
OF VENTRICULAR FLUID PRESSURE IN
NEUROSURGICAL PRACTICE

BY

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EJNAR MUNKSGAARD
COPENHAGEN 1960
Lundberg - ICP may be very unstable, longer recording is essential!
Monitoring of ICP and CPP. Are Mean Trends Sufficient?

CPP = ABP - ICP

[Graph showing ICP and CPP trends over days]
Patterns: low and stable ICP
Patterns: elevated and stable ICP
Patterns: B waves
Patterns: Waves related to increase in CBF
Patterns: Refractory intracranial hypertension
Hemodynamic characterization of intracranial pressure plateau waves in head-injured patients

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Fig. 1. Examples of recordings of ABP, ICP, and blood FV obtained in two head-injured patients developing ICP plateau waves.  A: The plateau wave was initiated by a short-term decrease in ABP.  B: The ABP before the wave was stable, but ICP waves (B-waves) were recorded.
TABLE 1
Mean values of pressure and hemodynamic parameters found in eight patients before, during, and after a plateau wave*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Before</th>
<th>During</th>
<th>After</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean ICP (mm Hg)</td>
<td>25.9 ± 5.7</td>
<td>52.3 ± 5.6</td>
<td>21.8 ± 7.2</td>
<td>0.018</td>
</tr>
<tr>
<td>mean CPP (mm Hg)</td>
<td>62.5 ± 6.8</td>
<td>34.1 ± 4.7</td>
<td>65.5 ± 9.4</td>
<td>0.008</td>
</tr>
<tr>
<td>mean FV (cm/sec)</td>
<td>52.8 ± 19.5</td>
<td>42.5 ± 22.3</td>
<td>53.3 ± 15.6</td>
<td>0.022</td>
</tr>
<tr>
<td>Fva (cm/sec)</td>
<td>44.5 ± 21.5</td>
<td>55.9 ± 28.1</td>
<td>32.1 ± 12.3</td>
<td>0.03</td>
</tr>
<tr>
<td>ICPa (mm Hg)</td>
<td>5.7 ± 2.1</td>
<td>16.5 ± 4.4</td>
<td>3.9 ± 1.6</td>
<td>0.022</td>
</tr>
<tr>
<td>ABPa (mm Hg)</td>
<td>33.7 ± 8.3</td>
<td>32.0 ± 5.7</td>
<td>31.4 ± 3.5</td>
<td>NS</td>
</tr>
<tr>
<td>mean ABP (mm Hg)</td>
<td>88.5 ± 6.9</td>
<td>86.5 ± 8.4</td>
<td>87.3 ± 7.9</td>
<td>NS</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>73.3 ± 18.6</td>
<td>70.1 ± 19.0</td>
<td>84.6 ± 19.7</td>
<td>NS</td>
</tr>
<tr>
<td>PI</td>
<td>1.66 ± 0.31</td>
<td>2.55 ± 0.49</td>
<td>1.56 ± 0.35</td>
<td>0.034</td>
</tr>
<tr>
<td>CVR (mm Hg/[cm/sec])</td>
<td>1.34 ± 0.54</td>
<td>0.98 ± 0.45</td>
<td>1.72 ± 0.76</td>
<td>0.022</td>
</tr>
</tbody>
</table>

*Fig. 3. Tracings showing the dynamic behavior of pulse amplitudes of blood FV (Fva) and intracranial pressure (ICPa) during a plateau wave.
FIG. 4. Recordings showing the distinctive changes in ICP and FV pulsatile components before (left) and on the top (right) of a plateau wave.
Plateau Waves in Head Injured Patients Requiring Neurocritical Care

Gianluca Castellani · Christian Zweifel · Dong-Joo Kim · Emmanuel Carrera · Danila K. Radolovich · Piotr Smielewski · Peter J. Hutchinson · John D. Pickard · Marek Czosnyka

\[ R = 0.42; p < 0.0001 \]
Long plateau wave – clear and present dager
Plateau waves: interaction with brain tissue oxygen content
Termination of ICP plateau wave by manual hyperventilation:
Low and stable ICP, plateau, plateau, plateau, plateau, plateau... and died
Intracranial pressure dynamics: changes of bandwidth as an indicator of cerebrovascular tension

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2.3. Analysis methods

Using MATLAB Systems Identification Toolbox, an autoregressive moving average technique was used to construct the black box model from 8-s recordings of ABP and ICP based on a system difference equation of the form

\[ X(t) + a_1 * X(t-T) + a_2 * X(t-2T) = b_1 * U(t) \]
\[ + b_2 * U(t-T) \]

In the above equation, \( X(t) \) and \( U(t) \) represent ICP and ABP, and \( T \) represents the sampling epoch of 4 ms.

Fig. 2. Second order circuit model of intracranial pressure dynamics and cerebral hemodynamics. This model is a modification of a previously proposed model by Ursino [16]. Two parameter values were changed to implement simulations for the piglet. Arterial–arteriolar resistance and compliance were changed from nominal values used for simulations for the adult human to 20 mmHg·s/cm³ and 0.1 cm³/mmHg, respectively. Other parameters are similar to those previously published [16].
Hypothesis: HMF up = CVR down

**Table 1** Overall mean values (±SD) values of ABP, ICP, CPP, HMF, simulated resistance of the arterial–arteriolar bed and correlation of HMF value with bed resistance

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number</th>
<th>ABP (±SD, mmHg)</th>
<th>ICP (±SD, mmHg)</th>
<th>CPP (±SD, mmHg)</th>
<th>HMF (±SD, Hz)</th>
<th>Sim. resist. (±SD, mmHg ml(^{-1}) s(^{-1}))</th>
<th>SimR vs CPP r value (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plateau wave</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Prior</td>
<td>5</td>
<td>100.7 (±13.9)</td>
<td>27.1 (±2.4)</td>
<td>73.6 (±2.5)</td>
<td>7.5 (±1.1)</td>
<td>8.6 (±1.1)</td>
<td>0.97 (±0.01)(^c)</td>
</tr>
<tr>
<td>During</td>
<td>5</td>
<td>108.5 (±9.6)</td>
<td>44.4 (±4.4)(^a)</td>
<td>67.1 (±3.1)(^b)</td>
<td>15.3 (±3.0)(^a)</td>
<td>4.1 (±1.3)(^a)</td>
<td>0.98 (±0.02)(^c)</td>
</tr>
<tr>
<td>After</td>
<td>5</td>
<td>100.4 (±7.1)</td>
<td>25.7 (±3.1)(^b)</td>
<td>76.1 (±3.2)(^a)</td>
<td>6.9 (±2.1)(^a)</td>
<td>9.8 (±1.3)(^a)</td>
<td>0.97 (±0.02)(^c)</td>
</tr>
</tbody>
</table>
Regular vasogenic waves: B waves (Slow waves), respiratory and pulse

ICP mmHg

1 min

ICP mmHg

10 sec

ICP mmHg

3 sec
Slow vasogenic repetitive waves – B waves

ICP [mm Hg]

ABP [mm Hg]

Infusion with rate of 1.5 ml/min

ICP [mmHg]

HB [µmol/L]

1 min

Time
During B waves elevation of ICP seems to be synchronous with elevation of CBF.
B waves in ICP are coherent with waves in CBF
Slow waves increase their intensity when mean ICP increases: higher frequencies damped using MA filter - infusion test
Head injury - patients sedated, ventilated. Usually no or weak B waves
Slow waves and outcome after head injury
Slow waves can be also seen in ABP and ICP- sometimes phase-shifted
B waves - periods of silence and periods of regular waves
Long term monitoring of ICP - hydrocephalus
Respiratory component in mechanically ventilated patients
Phase shift between ABP and ICP at respiratory rate
Relationship between phase shift and outcome and mean ICP

250 patients after TBI

Thanks to Mr. P. Lewis

Dose ICP = field above ICP>20 mm Hg

It correlates with outcome. It obviously correlates with a time of NCCU stay
What we have not discussed today is ICP pulse waveform, but it will be featured in details in following lectures.

Message to take home:
1. ICP is more than a number
2. ‘Hyperaemic waves’
3. Waves caused by rapid changes in ABP
5. Waves: slow (B waves), plateau waves
6. Respiratory wave- potentially useful in ventilated patients