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
Patterns: low and stable ICP
Patterns: elevated and stable ICP
Patterns: B waves
Patterns: Waves related to increase in CBF
Patterns: Refractory intracranial hypertension
Another 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>Plateau Wave</th>
<th>Before</th>
<th>During</th>
<th>After</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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 danger
Plateau waves: interaction with brain tissue oxygen content

1 hour
Termination of ICP plateau wave by manual hyperventilation:
Low and stable ICP, plateau, plateau, plateau, plateau, plateau... and died
ICP can be highly dynamic: There is a need for continuous monitoring.

Sometimes is less dramatic...

Intracranial Pressure - More than a Number
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

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

(1)

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>
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<td></td>
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<td></td>
</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)</td>
</tr>
<tr>
<td>During</td>
<td>5</td>
<td>108.5 (±9.6)</td>
<td>44.4 (±4.4)</td>
<td>67.1 (±3.1)</td>
<td>15.3 (±3.0)</td>
<td>4.1 (±1.3)</td>
<td>0.98 (±0.02)</td>
</tr>
<tr>
<td>After</td>
<td>5</td>
<td>100.4 (±7.1)</td>
<td>25.7 (±3.1)</td>
<td>76.1 (±3.2)</td>
<td>6.9 (±2.1)</td>
<td>9.8 (±1.3)</td>
<td>0.97 (±0.02)</td>
</tr>
</tbody>
</table>

*Note: a, b, c indicate significant differences*
Regular vasogenic waves: B waves (Slow waves), respiratory and pulse

ICP

mmHg

1 min

10 sec

3 sec
Slow vasogenic repetitive waves – B waves
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

ICP

mmHg

Spectrum
Long term monitoring of ICP- hydrocephalus
Respiratory component in mechanically ventilated patients

![Graph showing ICP and spectrum in mmHg over time]
Phase shift between ABP and ICP at respiratory rate

ICP

mmHg

ICP spectrum

ABP/ICP Phase shift
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
A Trial of Intracranial-Pressure Monitoring in Traumatic Brain Injury

Randall M. Chesnut, M.D., Nancy Temkin, Ph.D., Nancy Carney, Ph.D., Sureyya Dikmen, Ph.D., Carlos Rondina, M.D., Walter Videtta, M.D., Gustavo Petroni, M.D., Silvia Lujan, M.D., Jim Pridgeon, M.H.A., Jason Barber, M.S., Joan Machamer, M.A., Kelley Chaddock, B.A., Juanita M. Celix, M.D., Marianna Chernic, Ph.D., and Terence Hendrix, B.A.

• Hypothesis: a management protocol based on the use of ICP monitoring would result in reduced mortality and improved neuropsychological and functional recovery at 6 months.

No difference! 40% mortality

Thanks to Mr. Angelos Kolias
End-hour ICP compared to hour-averaged ICP – 5 days recording after TBI

Only 50% of changes in averaged ICP can be illustrated by end-hour ICP!!!
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