Impedance Cardiography (ICG)

Method, Technology and Validity
Hemodynamic Basics

Cardiovascular System

Flow

Pressure

Resistance

Cardiac Output (CO)

Mean arterial pressure (MAP)

Variable resistance (SVR)

Left ventricle

Elastic arteries / Aorta

Arterioles

SVR = MAP / CO

MAP = CO \times SVR

CO = MAP / SVR
Hemodynamic Basics

Parameters of Hemodynamics

Pressure

Blood Pressure (BP)
Force against vessel walls

Flow

Cardiac Output (CO)
Liters of blood pumped by heart in one minute

Resistance

Systemic Vascular Resistance (SVR)
Force that must be overcome to expel blood from the heart
**Thermodilution**

**Typical Invasive Hemodynamic Monitoring**

**Application:**
- Pulmonary artery catheter (PAC)
- Bolus application with cold water (10°C, 5-10 ml) into right atrium
- Recording of temperature in the pulmonary artery

**Problems:**
- Highly invasive (risk of bleedings, thrombosis and ruptures)
- Non continuous
- Cost-intensive
Impedance Cardiography (ICG)
Non-invasive Beat-to-beat Hemodynamic Monitoring

- Aortic valve is closed
- No blood flow in the aorta
- Red blood cells are orientated randomly

- Aortic valve opens
- Blood flow in the aorta (Windkessel function)
- Alignment of red blood cells

Sources of the measured impedance change
Impedance Cardiography (ICG)

ICG waveform and fiducial points

- Automatic detection of fiducial points
- Calculation of hemodynamic parameters (e.g. Stroke Volume [SV], Cardiac Output [CO], Thoracic Fluid Content [TFC])

**ICG waveform and fiducial points**

- **A-wave**: Contraction of atrium
- **B**: Opening of aortic valve
- **C**: Max. systolic flow
- **X**: Closing of aortic valve
- **O**: Opening of mitral valve
- **PEP**: Pre-Ejection Period
- **LVET**: Left Ventricular Ejection Time
- **$dZ_{max}$**: ICG Amplitude

**Diagram**

- ECG waveform
- ICG waveform
- **A-wave**
- **B**: Pre-Ejection Period
- **C**: Max. systolic flow
- **X**: Closing of aortic valve
- **O**: Opening of mitral valve
- **dZ_{max}**: ICG Amplitude
Impedance Cardiography (ICG)

Equation for Stroke Volume Estimation

\[ SV = V_{EPT} \cdot \frac{dZ_{max}}{Z_0} \cdot LVET \]

\[ V_{EPT\ (male)} = \frac{(0.17 \cdot H)^3}{4.25} \cdot \frac{W}{0.524 \cdot H - 16.58} \]

\[ V_{EPT\ (female)} = \frac{(0.17 \cdot H)^3}{4.25} \cdot \frac{W}{0.524 \cdot H - 26.58} \]

\( SV \quad \text{Stroke Volume} \)

\( V_{EPT} \quad \text{Patient related parameter (depending on weight, height, gender, ACM)} \)

\( dZ_{max} \quad \text{Amplitude of the systolic wave of the ICG} \)

\( Z_0 \quad \text{Base impedance (overall impedance of the thorax)} \)

\( LVET \quad \text{Left Ventricular Ejection Time: time interval between opening and closing of the aortic valve, validated by ACM [ms]} \)

\( W \quad \text{Weight of patient [kg]} \)

\( H \quad \text{Height of patient [cm]} \)

Bernstein D.P., *Crit Care Med*, 1986
Impedance Cardiography (ICG)

ACM – Arterial Compliance Modulation

Latest ICG technology for higher accuracy

- Earlobe sensor for registration of peripheral pulse wave
- Calculation of aortic compliance based on pulse wave velocity and curve shape parameters
- Detection of true X-point
Impedance Cardiography (ICG)

ACM – Arterial Compliance Modulation

How does ACM work?

Invasive aortic pressure curve allows accurate detection of aortic valve closing

ACM curve clearly reflects the fiducial points of the aortic pressure curve and can be measured non-invasively

Based on ACM the true X-point in the ICG signal can be defined
Impedance Cardiography (ICG)

ACM – Arterial Compliance Modulation

Result of ACM technology – stable and accurate LVET
# Impedance Cardiography (ICG)

ICG Hemodynamic Parameters

<table>
<thead>
<tr>
<th>Flow</th>
<th>Stroke Volume / Index (SV / SI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cardiac Output / Index (CO / CI)</td>
</tr>
<tr>
<td>Resistance</td>
<td>Systemic Vascular Resistance /</td>
</tr>
<tr>
<td></td>
<td>Index (SVR / SVRI)</td>
</tr>
<tr>
<td>Contractility</td>
<td>Systolic Time Ratio (STR)</td>
</tr>
<tr>
<td></td>
<td>Pre-ejection Period (PEP)</td>
</tr>
<tr>
<td></td>
<td>LV Ejection Time (LVET)</td>
</tr>
<tr>
<td></td>
<td>Velocity Index (VI)</td>
</tr>
<tr>
<td></td>
<td>Acceleration Index (ACI)</td>
</tr>
<tr>
<td>Fluid</td>
<td>Thoracic Fluid Content (TFC)</td>
</tr>
</tbody>
</table>
Impedance Cardiography (ICG)
Hemodynamic Components and Implications for Treatment

Cardiac Output (CO)

Heart rate (HR)
- (-) Neg. Chronotropes
  (+) Pos. Chronotropes

Stroke Volume (SV)
- Preload Fluid
  (-) Neg. Diuretics
  (+) Volume Expanders
- Afterload Resistance
  (-) Vasodilators
  (+) Vasoconstrictors
- Contractility
  (-) Neg. Inotropes
  (+) Pos. Inotropes
Impedance Cardiography (ICG)

Accuracy

Richard Summers, et al. / Academic Emergency Medicine, 2003
- Multicenter study including 680 patients comparing TD and ICG
- CO mean bias ± SD: -0.124 ± 0.75 (l/min)

Albert, et al. / America Journal of Critical Care, 2004
- Study including 29 patients with CHF comparing TD and ICG
- CO mean bias ± SD: -0.08 ± 0.26 (l/min) and correlation of r=0.89 to TD

- Study including 53 patients comparing TD and ICG
- CO mean bias ± SD: -0.18 ± 1.09 (l/min) and correlation of r=0.81 to TD
Impedance Cardiography (ICG)
ICG Reproducibility

N = 96 stable outpatient cardiac rehab patients

“...highly reproducible on same-day...show device sensitivity to normal hemodynamic changes on inter-day measurements...provides a baseline for objective determination of responses to therapeutic interventions.”

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Day 1 vs. Day 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95% conf. int.</td>
</tr>
<tr>
<td>SI</td>
<td>39.9 – 44.3</td>
</tr>
<tr>
<td>CI</td>
<td>2.7 – 3.0</td>
</tr>
<tr>
<td>VI</td>
<td>40 – 50</td>
</tr>
<tr>
<td>SVRI</td>
<td>1921 – 2235</td>
</tr>
<tr>
<td>TFC</td>
<td>32 – 34</td>
</tr>
</tbody>
</table>

### Impedance Cardiography (ICG)

#### Reproducibility: ICG vs. Thermodilution (TD)

N = 52 post-CABG patients with 3 sequential TD and ICG measurements

“…superior intrapatient reproducibility compared with thermodilution via PAC.”

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Correlation (R value)</th>
<th>Stand. Dev. (l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TD vs. TD</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TD 2 vs. TD 1</td>
<td>0.83</td>
<td>1.02</td>
</tr>
<tr>
<td>TD 3 vs. TD 2</td>
<td>0.84</td>
<td>1.01</td>
</tr>
<tr>
<td>TD 3 vs. TD 1</td>
<td>0.83</td>
<td>1.07</td>
</tr>
<tr>
<td><strong>ICG vs. ICG</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICG 2 vs. ICG 1</td>
<td>0.97</td>
<td>0.44</td>
</tr>
<tr>
<td>ICG 3 vs. ICG 2</td>
<td>0.98</td>
<td>0.39</td>
</tr>
<tr>
<td>ICG 3 vs. ICG 1</td>
<td>0.97</td>
<td>0.43</td>
</tr>
</tbody>
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Impedance Cardiography (ICG)
ICG Limitations

Physical

- Height: between 1.20 m and 2.30 m
- Weight: between 30 kg and 155 kg
  (Note: No age limit, just height and weight)

Precautions

- HR > 250 bpm
- Septic shock (end stage sepsis)
- Severe aortic sclerosis
- Severe aortic valve regurgitation
- Extremely high blood pressure (MAP > 130)
- Cardiac arrhythmia
- Intra-aortic balloon pump
Impedance Cardiography (ICG)
Applications of ICG

- Monitoring
- Hypertension Management
- Cardiovascular Diagnosis
- Pacemaker Adjustment
- Fluid Management