BSL PRO Lesson H21: Impedance Cardiography

Overview

Impedance Cardiography

Cardiac Output can be determined noninvasively with electrical bio-impedance measurement techniques. Electrical bio-impedance is simply the characteristic impedance of a volume of tissue and fluid. In the case of Cardiac Output measures, the relevant tissue includes the heart and the immediate surrounding volume of the thorax; the relevant fluid is blood.

The electrical impedance of the thorax can be thought of as composed of two types of impedances:

1. The base impedance ($Z_0$) corresponding to non-time varying tissues, such as muscle, bone, and fat. $Z_0$ is measured when the pulsatile volume is minimal.

2. The impedance ($\Delta Z$) corresponding to time-varying fluid volume (blood).

The electrical bio-impedance of the thorax [$Z(t)$] cyclically drops with each pulsatile volume of blood ejected from the heart:

Data collected from a subject using the referenced set-up procedure. Note that $dZ/dt$ maximum is determined on a cycle by cycle basis from the raw $dZ/dt$ waveform. Similarly, heart rate (BPM) is derived from the raw ECG waveform.
\[ Z(t) = Z_0 - \delta Z \]

**Where:**

- \( Z_0 \) = base impedance corresponding to non-time-varying tissues
- \( \delta Z \) = impedance corresponding to time-varying fluid volume

The SS31L sensor can be used to measure \( Z(t) \) directly. In the case of Cardiac Output, \( \delta Z \) is empirically determined to be:

\[ \delta Z = T \times \frac{dZ}{dt_{(max)}} \]

**Where:**

- \( T \) = Systolic [LVET] ejection time (seconds)
- \( \frac{dZ}{dt_{(max)}} \) = Magnitude of the largest impedance change during Systole (Ohms/sec)

The pulsatile volume of blood ejected by the heart is called the Stroke Volume (SV). The expression relating SV to \( Z_0 \), \( T \) and \( \frac{dZ}{dt} \) is:

\[ SV = R \times \left( \frac{L^2}{Z_0^2} \right) \times T \times \frac{dZ}{dt_{(max)}} \]

**Where:**

- \( SV \) = Stroke volume (ml)
- \( R \) = Resistivity of blood (Ohms·cm)
- \( L \) = Length between inner band electrodes (cm)

Cardiac Output (CO) is related to SV as follows:

\[ CO = SV \times HR \]

**Where:**

- \( CO \) = Cardiac Output (liters/minute)
- \( HR \) = heart rate (BPM)

The SS31L records the parameters associated with CO measurements. The SS31L incorporates a precision high frequency current source, which injects a very small (100µA rms or 400µA rms) current through the measurement tissue volume defined by the placement of a set of current source electrodes. A separate set of monitoring electrodes then measures the voltage developed across the tissue volume. Because the current is constant, the voltage measured is proportional to the characteristics of the biological impedance of the tissue volume.

The SS31L measures impedance. The SS31L is capable of recording impedances at four different operational frequencies, from 12.5kHz to 100kHz. Usually, CO measurements are performed at a measurement frequency of either 50 kHz or 100kHz.

**Cardiac Output Related Statistics**


- \( Z_0 \) = Base Thoracic Impedance
  - Males: 20-30 ohms, Females: 25-35 ohms
- \( \frac{dZ}{dt} \) = Impedance Change
  - 0.8 – 2.5 ohms/sec
- \( T \) = Ventricular Ejection Time
  - 0.25 – 0.35 seconds
- \( PEP \) = Pre-ejection Period
  - 0.05 – 0.12 seconds
- \( SV \) = Stroke Volume
  - 60-100 ml/beat
- \( CO \) = Cardiac Output
  - 4000-8000 ml/minute
- \( CI \) = Cardiac Index
  - 2.5-4.5 liters/min/ m² (indexed to body surface area)
Cardiac Output measures are relative and sensitive to electrode type, number and location. For example, band electrodes will generate different results than spot electrodes.

Further reading:
- Impedance Cardiography: Summary of Recent Literature, Wantagh Inc.

Objectives
1. To obtain stroke volume data.
2. To obtain cardiac output data.
3. Correlate heart valve opening/closing with cardiac output.

Equipment
- BIOPAC Noninvasive Cardiac Output Sensor (SS31L)
- BIOPAC Electrode Leads (SS2L)
- BIOPAC Stethoscope (SS30L)
- BIOPAC Bioimpedance Strip Electrodes (EL506)—Qty. 4
  Note Can substitute EL500 Paired Electrodes for relative measures
- BIOPAC Spot Electrodes (EL503)—Qty. 2
- Tape Measure or ruler
- Computer running Windows XP/Vista/7 or Mac OS X 10.4-10.6
- Biopac Student Lab PRO software
- BIOPAC Data Acquisition Unit (MP36/MP35/MP30)
  Note MP30 hardware is no longer supported in Mac BSL PRO v3.7.3 and higher

Setup

Hardware

1. Plug the SS31L-Z lead into CH 1 on the MP36/MP35/MP30 for impedance.
2. Plug the SS31L-dZ lead into CH 2 on the MP36/MP35/MP30 for derivative impedance.
3. Plug the SS2L lead into CH 3 on the MP36/MP35/MP30 for ECG.
4. Plug the SS30L microphone into CH 4 on the MP36/MP35/MP30 for Left Ventricular Ejection Time (T) value.
**Electrode Selection**

Cardiac Output measures are relative and sensitive to electrode type, number and location. For example, strip or band electrodes will generate different results than spot electrodes. Regardless of electrode selection, Lead positions should be maintained as described in steps 4 and 5 below. Electrode selection may, however, require Scaling adjustments as follows:

- This lesson uses bioimpedance strip electrodes (EL506) and disposable spot electrodes (EL503 for Lead II). The template scaling is optimized for these electrodes.
- If you use band electrodes (circularly distributed for each lead/subject contact), you can still use the template scaling.
- If paired electrodes are used, you will need to adjust the template scaling (as detailed in Software setup below).

1. Place two EL506 strip electrodes on the back of the neck, and two on the lower back as shown below.

<table>
<thead>
<tr>
<th>Color</th>
<th>Lead</th>
<th>EL506 Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>white</td>
<td>I+</td>
<td>Neck, top</td>
</tr>
<tr>
<td>red</td>
<td>V+</td>
<td>Neck, bottom</td>
</tr>
<tr>
<td>green</td>
<td>V-</td>
<td>Back, top</td>
</tr>
<tr>
<td>black</td>
<td>I-</td>
<td>back, bottom</td>
</tr>
</tbody>
</table>

2. Measure the vertical distance (in centimeters) between the upper and lower voltage sensing electrodes and note this value as "L" for later use in the Expression for Stroke volume.

3. Place one EL503 electrode on the right wrist and one above the left ankle (Lead II without ground).

4. Connect the SS31L leads according to the following color guides shown above.

5. Connect the SS2L lead as follows and **DO NOT CONNECT THE SS2L GROUND!**

<table>
<thead>
<tr>
<th>Color</th>
<th>Lead</th>
<th>EL503 Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>white</td>
<td>-</td>
<td>right wrist</td>
</tr>
<tr>
<td>red</td>
<td>+</td>
<td>left ankle</td>
</tr>
<tr>
<td>black</td>
<td></td>
<td>ground <strong>DO NOT CONNECT!</strong></td>
</tr>
</tbody>
</table>

6. Position the SS30L to optimally detect the opening and closing of the aortic valve, for positive definition of the Left Ventricular Ejection Time (T).

- In practice, there are many methods for the determination of (T). All of these methods are somewhat ambiguous, when one attempts to extract (T) from specific points on a waveform, whether using the phonocardiogram or the dZ/dt waveform itself, or in concert with the electrocardiogram. This lesson determines (T) via heart sounds; for precise guidelines, see Application Note #199 - Impedance Cardiography and Pre-ejection Period 📝.
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Software

1. Launch the BSL PRO software on the host computer.
   - The program should create a new "Untitled1" window.

2. Open the Impedance Cardiography Template by choosing File > Open > choose Files of type: Graph Template (*GTL) > File name: "h21.gtl"
   - The template will establish the required settings.

3. Adjust Scaling, if necessary: Standard scaling, as preset in the h21.gtl graph template, is shown below:

   ![Scaling Parameters](image)

   - If you did not use EL506 Bioimpedance Strip electrodes or band electrodes, adjust the Scaling so results will more closely approximate results from strip or band electrodes.

4. Save As the desired file name.

Calibration

No calibration required.

Recording

**Hints for minimizing measurement error:**

A. IMPORTANT: The SS31L is very sensitive to motion artifact—subject must minimize movement.
B. Electrodes should be in place at least 5 minutes prior to recording.

Segment 1: LVET Determination

1. Position the SS30L stethoscope for accurate detection of the heart sounds.

2. Press the Start button in the PRO software.

3. After 30-60 seconds, press the Stop button in the PRO software.

4. Measure the Left Ventricular Ejection Time (T).
In any particular ECG complex you will see two pulses of sound. Pick a particularly clean set of pulses from any one complex.

- Sweep the cursor to bridge from peak to peak in the filtered (40-60 Hz) heart sounds graph.
- Note the delta t measurement, which indicates the time from aortic valve opening to closing. This value is typically between 0.2 and 0.4 seconds.

5. Click on MP35/MP30 > Setup Channels.
6. Click on the wrench icon for calculation channel C5 Stroke Volume.

   - Enter the length between the inner band electrodes (cm) in the Stroke Volume formula as "L" (shown as "28" in this sample Expression).
   - Enter the LVET value in the Stroke Volume formula as "T" (shown as "0.300" in the sample Expression shown).
   - Click OK.

7. Ctrl-click on the CH4 channel box to hide the stethoscope (heart sounds) waveform.

Segment 2: Subject Seated

1. Have the subject sit down.
2. Press the Start button in the PRO software.
3. Insert a marker and label it “Seated.”
4. After 60 seconds (minimum), press Stop within the PRO software.

Segment 3: Subject Standing

1. Have the subject stand.
2. Press the Start button in the PRO software.
3. Insert a marker and label it “Standing.”
4. After 60 seconds (minimum), press Stop within the PRO software.

**Segment 4: Subject Lying Down**

1. Have the subject lie down.
2. Press the Start button in the PRO software.
3. Insert a marker and label it “Lying down.”
4. After 60 seconds (minimum), press Stop within the PRO software.

**Optional Segments:**

- Record during visual stimulation.
- Disconnect the cables and then ask the subject to perform several minutes of medium-to-strenuous exercise. Reattach the lead cables and record for several minutes; compare to baseline readings.

**Notes**

To save recorded data, choose File menu > Save As… > file type: BSL PRO files (*.ACQ) File name: (Enter Name) > Save button

To erase all recorded data (make sure you have saved it first), and begin from Time 0, choose: MP36/MP35/MP30 menu > Setup Acquisition > Click on "Reset"

**Analysis**

<table>
<thead>
<tr>
<th>Channel</th>
<th>Displays</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH 1</td>
<td>Z</td>
<td>from SS31L sensor</td>
</tr>
<tr>
<td>CH 2</td>
<td>dZ</td>
<td>from SS31L sensor</td>
</tr>
<tr>
<td>CH 3</td>
<td>ECG</td>
<td>from SS2L</td>
</tr>
<tr>
<td>CH 4</td>
<td>Stethoscope</td>
<td>from SS30L Stethoscope</td>
</tr>
</tbody>
</table>
| CH 40   | dZ filtered (optional) | from C1 = Lowpass filter of CH 2  
This filter (10 Hz, Q = 0.707) on Z(t) cleans up any residual noise on the Z(t) waveform prior to differentiating. This filter is optional, depending on signal quality. |
| CH 43   | dz max | from C4= Peak maximum, via Rate, determination on CH 41  
Determine the cycle by cycle peak maximum of dZ/dt. |
| CH 44   | Stroke Volume | from C5 = Expression Evaluator: SV = R x (L²/Z₀²) x T x dZ/dt(max) |
| CH 45   | Heart Rate (BPM) | from C6 = Determines the cycle by cycle BPM of the ECG signal on CH 3. |
| CH 46   | Cardiac Output | from C7 = Expression Evaluator: CO = SV x HR |

Take the Cardiac Output, Stroke Volume, and Heart Rate (BPM) value measurements and compare for the various conditions, i.e. sitting, standing, lying down.

For detailed analysis, see BIOPAC App Note #199 - Impedance Cardiography and Pre-ejection Period

- AS199 was compiled by Ryan A. Brown and Jason A. DeCaro, Laboratory for Comparative Human Biology (LCHB), Department of Anthropology, Emory University.
Appendix

GRAPH TEMPLATE SETTINGS

Click here to open a PDF of the graph template file settings. The BSL PRO Graph Template file automatically establishes the settings shown in the table.