Ultra-Convenient Cardiovascular Monitoring with Heartbeat-Induced Body Motions

Jin-Oh Hahn (Maryland), Omer Inan (Georgia Tech), Ramakrishna Mukkamala (Michigan State)

**BCG: Heartbeat-Induced Body Motion**

- Ballistocardiogram (BCG) is heartbeat-induced body motion (Fig. 1).
- BCG is closely associated with cardiac function. Further, BCG is amenable to ultra-convenient measurement. Hence, BCG is anticipated to drastically advance cardiovascular (CV) health monitoring. However, its impact on CV health monitoring has been limited due to limited physical understanding.

**Ultra-Convenient Blood Pressure Tracking with BCG**

- Big Picture: To measure BP surrogate(s) from BCG and calibrate to BP!
- Correlation and Best-Case BP Measurement Errors
  - Our mathematical modeling\(^1\) revealed that the primary mechanism for the genesis of BCG is aortic blood pressure (BP) gradients (Fig. 2).
    1) A simple mathematical modeling analysis reveals that the primary mechanism responsible for the genesis of BCG is blood pressure (BP) gradients in the ascending and descending aorta (Fig. 2(a)).
    2) Based on the revealed mechanism, BCG waveform may have the following implications for clinically significant CV parameters (Fig. 2(b)-(d)): (a) I wave is related to the onset of ascending aortic BP (b) I-J interval is related to aortic pulse transit time (c) J amplitude is related to aortic pulse pressure (d) J-K amplitude is related to distal pulse pressure
    3) The mathematical (a) model could predict waveforms similar to BCG from experimental aortic BP waveforms obtained from humans (Fig. 2(e)).

**BCG: Physiological Mechanism**

- Our mathematical modeling\(^1\) revealed that the primary mechanism for the genesis of BCG is aortic blood pressure (BP) gradients (Fig. 2).
  1) A simple mathematical modeling analysis reveals that the primary mechanism responsible for the genesis of BCG is blood pressure (BP) gradients in the ascending and descending aorta (Fig. 2(a)).
  2) Based on the revealed mechanism, BCG waveform may have the following implications for clinically significant CV parameters (Fig. 2(b)-(d)): (a) I wave is related to the onset of ascending aortic BP (b) I-J interval is related to aortic pulse transit time (c) J amplitude is related to aortic pulse pressure (d) J-K amplitude is related to distal pulse pressure
  3) The mathematical (a) model could predict waveforms similar to BCG from experimental aortic BP waveforms obtained from humans (Fig. 2(e)).

**Trend of BP and BP Surrogates in Response to BP-Perturbing Interventions**

- Trend of BP and BP Surrogates in Response to BP-Perturbing Interventions
  - BP Error with 1-Point Subject-Specific Calibration
    
<table>
<thead>
<tr>
<th>mmHg</th>
<th>BCG PTT</th>
<th>BCG I-J Interval</th>
<th>PAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>9.2+/-.1.0</td>
<td>11.3+/-.1.2</td>
<td>14.1+/-.4</td>
</tr>
<tr>
<td>Mean AE</td>
<td>7.7</td>
<td>9.6</td>
<td>11.1</td>
</tr>
</tbody>
</table>
  

This material is based on work supported by the U.S. National Institutes of Health under Grant U01EB018818-01. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Institutes of Health.