Pulse Wave Velocity & Pulse Pressure Estimation via Ultrasound Signals

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Hypertension or High Blood Pressure – Cardiovascular Risk Factor

Systolic BP (SP)

Stroke mortality (floating absolute risk and 95% CI)

Auscultation SP (mmHg)

Ischaemic heart disease mortality (floating absolute risk and 95% CI)

Age at risk:
- 80-89 years
- 70-79 years
- 60-69 years
- 50-59 years
- 40-49 years

[Prospective Studies Collaboration, Lancet, 2002]
Hypertension or High Blood Pressure – Accuracy of measurement

1. easyauscultation.com
2. 10.1126/scitranslmed.aap8674
3. Edwards Lifesciences
Pulse Pressure – Cardiovascular Risk Factor

Is Pulse Pressure Useful in Predicting Risk for Coronary Heart Disease? The Framingham Heart Study, Circulation 1999
Pulse Wave Velocity – Cardiovascular Risk Factor

Relation between blood pressure and pulse wave velocity for human arteries, PNAS 2018

[Arterial stiffness and cardiovascular events: The Framingham Heart Study, 2010]
Pulse Wave Velocity & Pulse Pressure – How to measure?

Device requires High Sampling rate, Difficult to measure Local Pulse Wave Velocity

Relation between blood pressure and pulse wave velocity for human arteries, PNAS 2018

Pressure waves

\[ PWV = \frac{L}{\Delta t} \quad (1) \]

Pulse Pressure = Systolic BP – Diastolic BP
Pulse Wave Velocity & Pulse Pressure – Flow Velocity-Area method: Theory

Relation between blood pressure and pulse wave velocity for human arteries, PNAS 2018

In the reflection free period, pressure waveform has forward waves only!

\[ \sqrt{A} = \left( \frac{\sqrt{\rho C}}{2} \right) V + \text{Constant} \]

\[ \text{Reflection free period} \]

\[ \text{Slope} = \frac{\sqrt{\rho C}}{2} \]

\[ \text{Blood flow velocity [m/s]} \]

\[ \text{Arterial area [mm]} \]

\[ \text{Area} (A) \]

\[ \text{Flow} (V) \]

Compliance (C)

Density of blood (\( \rho \))

\[ \text{PWV} = \frac{A}{\sqrt{2 \times \text{Slope}}} \]

\[ \text{PP} = \frac{\Delta A \times \rho}{4 \times \text{Slope}^2} \]
Pulse Wave Velocity & Pulse Pressure – Flow Velocity-Area method: Comparison

**Flow velocity – Area Algorithm (Proposed method)**

Assumes Compliance is a constant

\[
PWV = \sqrt{\frac{A}{2 \times \text{Slope}}}
\]

\[
VF = \text{Slope} = \frac{\sqrt{\rho C}}{2}
\]

\[
PP = \frac{\Delta A \times \rho}{4 \times \text{Slope}^2}
\]

**Volume flow rate\( (Q) \) – Area Algorithm (Reported in Literature)**

Assumes Pulse Wave Velocity is a constant

Reflection free period

\[
PWV = \text{Slope}
\]

\[
PP = \frac{\Delta A}{A_u} \times \rho \times \text{Slope}^2
\]
Pulse Wave Velocity & Pulse Pressure
–Flow Velocity-Area method: Ultrasound

Record data using ultrasound

Blood flow velocity (V) [m/s]
Arterial area (A) [mm^2]

~ 10 mm ~ 4 mm

A Non-invasive Central Arterial Pressure Waveform Estimation System using Ultrasonography for Real-time Monitoring, MIT Thesis 2018
Pulse Wave Velocity & Pulse Pressure – Flow Velocity-Area method: Algorithm

Step 1: Record data using ultrasound

Step 2: Extract a beat

Step 3: Fit a line in the reflection free period

Step 4: Estimate Pulse Wave velocity

Blood flow velocity ($V$) [m/s]

Arterial area ($A$) [mm$^2$]

$PWV = \sqrt{\frac{A}{2 \times \text{Slope}}}$

$PP = \frac{\Delta A \times \rho}{4 \times \text{Slope}^2}$
## Pulse Wave Velocity – Flow Velocity-Area method: Results

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Pulse Wave Velocity Estimation Algorithm (m/s)</th>
<th>Volume Flow Rate-Area Algorithm (From literature)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow Velocity-Area Algorithm (Proposed method)</td>
<td>Volume Flow Rate-Area Algorithm (From literature)</td>
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<td>1</td>
<td>3.96</td>
<td>4.12</td>
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<td>6.68</td>
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<tr>
<td>4</td>
<td>4.72</td>
<td>4.91</td>
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</table>

Flow Velocity-Area Algorithm assumes that “Compliance of the artery” is a constant

Volume Flow Rate-Area method assumes that “Pulse wave Velocity” is a constant
Pulse Pressure
–Flow Velocity-Area method: Results

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Pulse Pressure Estimation Algorithm (mmHg)</th>
<th>Reference Pulse Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area Flow Algorithm (Proposed method)</td>
<td>Volume Flow Rate-Area Algorithm (From literature)</td>
</tr>
<tr>
<td>1</td>
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<td>23</td>
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</table>

• Both the methods gave comparable results
• Take home message: We may assume PWV and Compliance as a constant !
Next Step: Estimate Absolute Blood Pressure – Transmission Line Model

Step 1: Record data using ultrasound

- Blood flow velocity (V) [m/s]
- Arterial area (A) [mm²]

Assumption:
Pulse Wave Velocity and Compliance is a constant

Blood Flow Velocity

\( Z_0, \beta \)

Length

Pressure

\( R_L \)

Estimate \( R_L \) using Transmission line and compliance equations

Absolute Mean Pressure
\( = R_L \times \text{Mean Flow} \)

\( Z_0 \) – Characteristic impedance
\( \beta \) – Propagation Constant
Summary

• Developed an algorithm to estimate pulse pressure and PWV using Flow Velocity-Area method.

• Results from this algorithms are comparable with other methods reported in the literature.

• Assuming PWV and Compliance is a constant maybe used in transmission line model of the artery model.
Thank You and Stay Safe !