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Arterial pressure measurement: Is the envelope curve of the oscillometric method influenced by arterial stiffness?

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Abstract. Measurement of peripheral arterial pressure using the oscillometric method is commonly used by professionals as well as by patients in their homes. This non invasive automatic method is fast, efficient and the required equipment is affordable with a low cost. The measurement method consists of obtaining parameters from a calibrated decreasing curve that is modulated by heart beats which appear when arterial pressure reaches the cuff pressure. Diastolic, mean and systolic pressures are obtained calculating particular instants from the heart beats envelope curve. In this article we analyze the envelope of this amplified curve to find out if its morphology is related to arterial stiffness in patients. We found, in 33 volunteers, that the envelope waveform width correlates to systolic pressure (r=0.4, p<0.05), to pulse pressure (r=0.6, p<0.05) and to pulse pressure normalized to systolic pressure (r=0.6, p<0.05). We believe that the morphology of the heart beats envelope curve obtained with the oscillometric method for peripheral pressure measurement depends on arterial stiffness and can be used to enhance pressure measurements.

1. Introduction
Arterial stiffness slowly progresses with age although it can be accelerated by other cardiovascular factors [1]. A non invasive method to estimate arterial stiffness is to measure the pulse wave velocity (PWV), that consist on measuring the traveling velocity of the pulse wave through a known distance between two points of the arterial system [2]. The rising of the PWV results in an early reflection of the pressure wave which increases the systolic pressure (SP) and decreases the diastolic pressure (DP), which results in an increase of pulse pressure (PP). Therefore, measurements of peripheral PP were used as stiffness indicators [2]. However, PP is influenced by other factors that are not directly related to arterial stiffness. PWV remains as an independent indicator of cardiovascular risk events but the available technology to measure it is now widely accessible [3].

Today there are automatic systems to measure peripheral pressure based on the oscillometric method. This non invasive systems measure the cuff pressure during deflation to identify the instants where arterial and cuff pressure match. At that moment, heart beats produce peaks that can be interpolated to conform an envelope curve that looks like a Gaussian bell. Recently, our research group developed a prototype to measure these curves.

In the present work, we use the deflating curve and its amplified version from a self made prototype to measure arterial pressure, based on the oscillometric method, to study the relationship between their morphology and some physiological variables related to arterial stiffness. We believe that the envelope curve is wider for patients with stiffer arteries.
2. Materials and methods

2.1. Acquisition

For this work a prototype module developed in the Favaloro University for peripheral arterial pressure measurement based in the oscillometric method was used. The device was validated with patients from different age ranges and homologated using a professional equipment (brunch SUN-UP, model AU6109). The prototype uses a pressure sensor to collect the oscillations coming from the cuff. Then it is connected to an instrumentation amplifier to fix the signal and send it to a microcontroller. The latter will create two pressure signals. The first one will be the calibrated absolute deflating curve. The second one is an amplified version, filtered with a high pass filter, which will show the small pulses created by heart beats modulating the cuff pressure (figure 1). The microcontroller is in charge of controlling the escape valve and the inflating compressor, digitalizing the two pressure signals described above and sending sampled data to a PC (Pentium II, 166MHz, 256M RAM).

The procedure is automatically controlled by the interaction between the microcontroller and the PC. To perform a measurement, the cuff has to be placed in the patient arm and the operator has to only initialize the automatic system. More detail about cuff and patient positions can be found in the corresponding guidelines [4]. At the beginning, the system will activate the compressor to inflate the cuff until it reaches a supra-systolic pressure. This procedure is done with the deflating valve closed. When the system reaches the maximum pressure the compressor is stopped and the linear deflating curve is registered while the pressure decreases slowly. A calibrated valve controls this decay.

At this time the sampling of the two pressure signals starts, the signals enter the system thru two different conversion channels. The sampling rate for each channel is 60Hz. The PC stores both signals until the pressure drops under 50mmHg, when the valve opens and fast deflating starts.

Pressure signals appear on the screen. The calibrated deflating curve appears at top and the amplified version at bottom. SP and DP are calculated using those curves.

![Pressure Curve](image1.png)

![Heart Beat Curve](image2.png)

Figure 1. Registered pressure signals. Top: calibrated deflating curve. Bottom: heart beats amplified and filtered by a high pass filter.

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Pressure signals appear on the screen. The calibrated deflating curve appears at top and the amplified version at bottom. SP and DP are calculated using those curves.
2.2 Algorithm used to estimate the envelope curve width.

Briefly, the algorithm starts interpolating the peaks from the amplified curve using a sixth order polynomial, figure 2. Those points create an envelope curve. The instant of the maximum value of this curve corresponds to the mean pressure (MP) in the calibrated deflating curve. Afterwards, SP and DP are estimated using threshold values on the left and on the right respectively. Threshold values were already estimated as the parameters that minimized the minimum square error with respect to the professional tensiometer (brunch SUN-UP, model AU6109).

![Pressure Curve](image1.png)

Figure 2. SP, MP and DP estimation

Finally, the algorithm calculates the heart rate (HR) using the peaks from the amplified signal. Once the measurement is finished all values (SP, MP, DP, HR) are shown on the screen and registered for processing purposes. The program also allows exporting the calculated values and the digitalized curves. The envelope curve width (ECW) was calculated from DP to SP points. Calculation of this parameter is shown in figure 3. In order to compare the non-calibrated curves from different volunteers, they were normalized to maximum values.

Taking into account our experience, we remarked patients with similar SP and DP values but with completely different envelope curves. The ECW allows extracting from this curve an important parameter to distinguish these patients. Patients with stiffer arteries are prone to present wider curves with higher ECW, while patients with elastic arteries would show thinner and peaked curves with lower ECW values. Using the same cuff and keeping the same deflating valve it is possible to obtain complementary information to the traditional pressure measurements trough this new parameter.

This study collected pressure data from 33 volunteers from different ages; the values were organized by age and expressed as mean ± standard deviation. Then, PP and PP/PS coefficients were calculated and the Pearson coefficient was used to evaluate the correlation between ECW with age, PP and PP/PS.
3. Results
The values for PP, PP/PS and ECW measured from the samples provided by the prototype are shown in table 1.

Table 1. Study’s population (N = 33). Pressure results organized by age. SP = systolic pressure. DP = diastolic pressure. PP = pulse pressure. ECW = surround curve width.

<table>
<thead>
<tr>
<th>Ages [years]</th>
<th>Mean±SD [years]</th>
<th>SP [mmHg]</th>
<th>DP [mmHg]</th>
<th>PP [mmHg]</th>
<th>PP/PS</th>
<th>ECW [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;25</td>
<td>18±2&lt;</td>
<td>118±10</td>
<td>73±7</td>
<td>45±4</td>
<td>0,38±0,01</td>
<td>9,1±1,8</td>
</tr>
<tr>
<td>25-35</td>
<td>33±4</td>
<td>125±16</td>
<td>74±7</td>
<td>50±11</td>
<td>0,40±0,03</td>
<td>11,7±2,4</td>
</tr>
<tr>
<td>35-50</td>
<td>44±5</td>
<td>129±7</td>
<td>74±7</td>
<td>45±3</td>
<td>0,37±0,03</td>
<td>8,5±2,3</td>
</tr>
<tr>
<td>50-60</td>
<td>54±2</td>
<td>127±17</td>
<td>82±11</td>
<td>45±8</td>
<td>0,35±0,03</td>
<td>9,6±2,2</td>
</tr>
<tr>
<td>&gt;60</td>
<td>73±10</td>
<td>150±18</td>
<td>91±12</td>
<td>58±8</td>
<td>0,39±0,04</td>
<td>10,0±0,4</td>
</tr>
</tbody>
</table>

Age was positively associated to SP (r=0.6, p<0.01) and to PP (r=0.4, p<0.05). The ECW positively correlated to PS (r=0.4, p<0.05), PP (r=0.6, p<0.01) and PP/PS (r=0.6, p<0.01). Those results are shown in figures 4, 5 and 6. No correlation was found between age and ECW.

Figure 3. Envelope curve width (ECW) determination
Figure 4. ECW Vs SP correlation (r=0.4)

Figure 5. ECW Vs PP correlation (r=0.6)
4. Discussion
This work shows the relation between the envelope curve, obtained using the oscillometric method to measure arterial pressure, and clinically used parameters that are influenced by arterial stiffness. The normalized curves were quantified using their width using an index called ECW. We believe arterial stiffness can influence the shape of the envelope curve and ECW might be used to simply estimate rigidity.

Age resulted associated to PS and PP as reported elsewhere [1-4]. Aging progressively raises arterial stiffness that can be partially reflected on pressure changes. According to our results over 33 volunteers including young and old persons, the ECW was higher for those with grater SP and PP. These indexes are traditionally associated to arterial stiffness. The coefficient PP/PS was also used as a normalized estimator. This parameter normalizes pulse pressure to PS allowing comparing patients with different maximum pressures. The calculated ECW was higher for increasing values of PP/PS. According to these results ECW was associated to indexes influenced by arterial stiffness.

This could indicate that the envelope curve registered with commonly used tensiometers can be used to detect increased arterial stiffness. Several limitations should be pointed out. The reason for using ECW as a stiffness indicator is based on the assumption that stiffer arteries would present, during the deflating phase of the cuff, a wider envelope curve. Nevertheless, ECW would always be a local estimator instead of a global indicator as it is measured in the arm. To validate this results it would be necessary to compare them to PWV measurements witch is widely used as an arterial stiffness global and independent indicator. Another way to calculate arterial stiffness is to simultaneously measure diameter, although its measurement requires complex technology. The aim of this study was to show that the envelope curve, probably available in traditional tensiometers, was modulated by arterial rigidity.

Another significant limitation of this study is the volunteer’s reduced number. Grater number of volunteers would be needed considering dispersions and methodological errors. This could partly explain the lack of correlation between ECW and age.

Finally, the oscillometric method is based on the SP, MP and DP estimation using the envelope curve that was also used to calculate ECW. Therefore any external factor, such as atmospheric pressure, escape valve and cuffs elasticity for instance will influence all this indexes together. Taking
into account that this method is widely implemented in professional equipments it is understandable to assume that the external factors would not particularly influence ECW measurement.

5. Conclusion
Our results show that in the oscillometric method used to calculate arterial pressure, the envelope curve is related to some rigidity indicators. The width of the envelope curve was greater for patients with increased SP, PP and PP/SP. These results would indicate that everyday measurement of peripheral pressure could be enhanced incorporating an arterial stiffness index with low effort. In order to validate this conclusion it is necessary to implement, in a greater number of patients, a protocol that includes a global and independent arterial stiffness index such as PWV.

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