Finger arterial pressure measurement with Finapres


Die Finapres-Wellenform kann jedoch so gefiltert werden, daß eine Brachials-Druckwelle zur Verfügung steht. Dadurch wird die Streuung der systolischen Werte unter der Infusion vasokonstriktorischer Pharmaka und dynamischen Belastungstests bis zur Erschöpfungsgrenze, Bedingungen unter denen die Präzision der Systolenmessung in der Literatur kritisiert wurde, reduziert.

Vor kurzem wurden Druckhöhenkorrekturtechniken (Level-Shift) entwickelt, welche eine Anpassung der Fingerdruckwerte nach oben oder unten an die systolischen und diastolischen Drücke mit Hilfe einer Regressionsgleichung erlauben. Dieses Verfahren führt ohne zusätzlichen Meßaufwand zu einer beachtlichen Verbesserung der Genauigkeit der systolischen, diastolischen und mittleren Druckwerte.

Abschließend wird demonstriert, wie die Qualität der Finapres-Messung mit Hilfe des Physiocal-Systems beurteilt werden kann.

Schlüsselwörter Fingerarteriendruck – Pulswellenformverzerrung – Verzerrungskorrektur – generalisierter Umkehrfilter – automatische Druckhochkorrektur – Qualitätskontrollpunkte

Summary Finger arterial pressure measurement with Finapres has been available since a decade. Its availability has promoted at least 300 methodological and research papers over these years, outlining the usefulness and the limitations of the method and the device. Finapres is based on the volume clamp method of Peñaz and the Physiocal criteria of Wesseling.

Tracking of intraarterial pressure is usually satisfactory even under conditions of strongly changing hemodynamics and high and very low blood pressures. Finapres accuracy is similar to that of other non-invasive methods. Systolic pressure levels scatter more than mean and diastolic levels. One source of error is physiologic and determined by the peripheral measurement site of the finger, causing pulse waveform distortion and a pressure gradient.

The Finapres waveform can be filtered, however, to obtain a brachial pressure wave. This decreases systolic scatter under vaso-constrictive drug infusion and dynamic exercise to exhaustion, conditions where precision of systolic tracking has been criticized in the literature.
Recently, level correction techniques were found which shift finger pressure up or down based on a regression equation with finger systolic and diastolic pressures. This procedure requires no additional measurements yet improves systolic, diastolic and mean level accuracy and precision remarkably.

Finally, we show how to judge the quality of a Finapres recording from the behavior of Physiocap.

Key words Finger arterial pressure – pulse waveform distortion – distortion correction – generalized inverse filter – automatic level correction – quality control points

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**Introduction**

In 1973, Jan Peñaz published his method (13) to measure continuous blood pressure in humans: a volume-clamp method of the arteries of a finger. Eleven years later the Physiocap criteria (17) were added to the volume-clamp method and both methods were combined in an instrument called Finapres, developed by TNO-BioMedical Instrumentation in the Netherlands. Methods and devices have been extensively tested, limitations have been charted and applications have been found in many areas of research and clinical care (18). But questions remained about how to judge the quality of a Finapres recording and how to reduce the differences with intrabrachial pressure waves. We describe techniques to resolve these questions.

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**Finapres methods**

In the volume-clamp method the size of the finger arteries is gauged with a photoelectric transmission plethysmograph mounted in an air inflatable cuff (13). Operation is as follows. If the size of the arteries increases under the cuff due to a blood pressure increase, as a consequence, more light is absorbed by the larger amount of blood and less light reaches the photodiode of the plethysmograph decreasing its output. This is detected by the servo system through comparison with a fixed, setpoint level, and counteracted by instantaneously bringing cuff air pressure up, thereby pressing the extra blood volume out again. Thus, blood volume, arterial size and transmural pressure are kept constant and cuff pressure follows blood pressure in the finger.

Ideally, cuff pressure should not just follow but be identical to blood pressure. If this is the case the difference between blood pressure and cuff pressure, called transmural pressure, is zero. At zero transmural pressure the arteries are unstretched. How can the unstretched state be calibrated noninvasively?

Physiocap (17) calibrates the unstretched size by temporarily interrupting the blood pressure measurement when cuff pressure is at a level half way between systolic and diastolic. Since blood pressure continues to pulse inside the artery transmural pressure and blood volume now change and a plethysmogram is observed and evaluated by a computer algorithm. From the amplitude and the shape of the plethysmogram a setpoint adjustment is computed and the unstretched size better approximated, after which the measurement is continued. Physiocap is repeated every 70 heart beats since the unstretched size may change due to variations in the tone of the smooth muscle in the finger arterial wall. Physiocap is repeated more frequently if smooth muscle activity changes rapidly.

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**Accuracy and tracking of changes**

Finapres recordings have been compared to intraradial or intrabrachial blood pressures in studies in anesthetized and in awake subjects. Reported accuracies differ somewhat between studies. Imholz et al. (11) summarized results. Finger arterial mean pressure measured with Finapres is 5 to 10 mm Hg lower than intraarterial pressure in the brachial artery. This is probably caused by a pressure gradient due to flow in the arteries of the arm and hand (3,19). The shape of the pressure pulsation in the finger differs from that in the brachial artery. Pulses are more undulatory in the finger and pulse pressure is greater (Fig. 1). When compared to intraradial pressure, which site is closer to the finger, pulse shape differences are less pronounced (15).

Blood pressure variations have been induced by surgical maneuvers, vasoactive drug administration, or cardiovascular maneuvers such as Valsalva straining, orthostasis and exercise to exhaustion. Finapres was reported to track changes in blood pressure well except in two studies (8,9) where blood pressure and heart rate were changed by the infusion of phenylephrine and by high intensity ergometer exercise. This tracking problem has been solved recently (7).

Measurements can be continued over periods as long as 24 h and by induction, therefore for indefinite periods of time without noticeable drift or change in accuracy (10). Continuous monitoring for such long periods imposed no major limitations in behavior of the subjects.
**Effects of a peripheral measurement**

Finger pressure pulsations, like radial or brachial ones, are distorted in waveform and amplified in pulse pressure when compared to aortic. These phenomena are primarily due to reflections of the pressure pulsations when they travel in the arterial system. Distortion has been described as early as 1925 (5, 6) and has been studied to the brachial and radial sites in detail recently (12). Pulse amplification is highest in the young but tends to disappear above 60 years of age.

In addition to pulse amplification there is a pressure gradient due to flow in the arteries. It cause peripheral mean pressure to be lower than in the aorta. The effect is stronger in the smaller peripheral arteries and, in contrast to amplification, appears to increase with the age of the subject (2, 14).

Pulse amplification and pressure gradient together cause finger mean pressure to be below that in the brachial artery or the aorta and pulse pressure to be amplified with respect to more proximal sites. This results in finger systolic pressure to be elevated in the young but to be about equal or even depressed in elderly subjects. Diastolic pressure in the finger is always lower than in more central arteries.

**Solutions**

We have used the intrabrachial and simultaneous finger pressure waveforms recorded in 53 subjects described in previous studies (2, 8, 14) to learn from their waveforms the characteristics of a filter that can transform the peripheral finger pressure waveform to a waveform that is close to the intrabrachial waveform. In addition, we compared finger to brachial pressure levels to learn how much to shift the finger waveform up or down to better approach brachial pressure levels.

*Filtering to brachial waveforms:* From the simultaneously recorded finger and intrabrachial waveforms a frequency-dependent transfer function was computed by dividing the finger by the brachial Fourier spectra. This function describes the linear distortion that a brachial pulsewave undergoes when traveling to the finger. A digital waveform filter was then constructed with a transfer function that, when multiplied with the geometric average transfer function produces an almost flat overall transfer function (Fig. 2). When each individual finger pulsewave is fed through the filter most of the linear distortion is

**Fig. 2** The transfer function from brachial to finger resonates at about 8 Hz (thin top trace). This causes oscillatory distortions of the finger wave. Distortion can be removed by a digital filter that has an anti-resonance at 8 Hz (bottom trace). The two transfer functions compensate each other almost perfectly to produce a desirably flat overall transfer function (thick trace).

**Abb. 2** Die Transferfunktion von brachial zu Finger zeigt eine Resonanz bei ca. 8 Hz (obere dünne Linie). Dies führt zu oszillatorischen Verzerrungen der Fingerwelle. Die Verzerrung kann durch einen digitalen Filter mit einer Gegenspannung bei 8 Hz (untere Linie) unterdrückt werden. Die beiden Transferfunktionen kompensieren sich nahezu vollständig gegenseitig und liefern so die gewünschte flache Gesamttransferfunktion (dicke Linie).
removed in the individual case, and an almost brachial pulsewave with correct pulse pressure results (Fig. 3).

**Level shift:** When the brachial, and the original and the filtered finger pressure levels are compared it appears that the original finger pressure levels are too low. After filtering they are too high. Since pulse pressures after filtering are correct, on average, it appears that a level shift of each filtered pulsewave would correct for the errors. A level shift by performing an upper arm cuff blood pressure reading is the subject of a recent study (4). When such a reading is not available it is possible to compute a pressure shift based on the filtered systolic and diastolic pressures. The formula is:

\[ p_s(t) = p(t) + A + Bp_d + Cp_s \]

in which \( p_s(t) \) is the filtered, level shifted (corrected) finger waveform as a function of time, \( p(t) \) is the filtered waveform, \( p_d \) is the filtered diastolic pressure, and \( p_s \) is the filtered systolic pressure. \( A \), \( B \) and \( C \) are regression coefficients. The results pooled for the group are listed in Table 1. Both mean error and scatter are reduced by the level shift. Corrected levels show no systematic offset from brachial and have a zero intercept (Fig. 4).

**Experiences**

The following experiences have generally been noted with commercial or TNO Finapres devices.

Differences between Ohmeda and TNO models

A small number of TNO Finapres Model 5 devices have been built and distributed with the permission of Ohmeda. One of these devices has flown in the German D-2 space flight (20). TNO devices behaved marginally different from the commercial Ohmeda Model 2300 NIBP (1) which was based on the TNO Model 4 device. Later Ohmeda devices were upgraded to TNO Model 5. Initial

![Table 1](image)

Table 1: Pressures and pressure differences in 53 subjects aged 22 - 83 years. Brachial and finger pressures and filtered and additionally level shifted finger pressures are listed. Pressure differences are with respect to intrabrachial. All numbers are mm Hg.

<table>
<thead>
<tr>
<th>Level/Druck</th>
<th>Brachials</th>
<th>Finger</th>
<th>Filtered</th>
<th>Shifted</th>
</tr>
</thead>
<tbody>
<tr>
<td>systolic/</td>
<td>169 ± 33</td>
<td>163 ± 29</td>
<td>177 ± 34</td>
<td>168 ± 33</td>
</tr>
<tr>
<td>systolic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>diastolic/</td>
<td>89 ± 17</td>
<td>83 ± 18</td>
<td>97 ± 24</td>
<td>89 ± 14</td>
</tr>
<tr>
<td>diastolic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean/</td>
<td>118 ± 22</td>
<td>104 ± 21</td>
<td>125 ± 24</td>
<td>116 ± 20</td>
</tr>
<tr>
<td>Mittel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pulse/</td>
<td>79 ± 23</td>
<td>83 ± 23</td>
<td>79 ± 24</td>
<td>79 ± 24</td>
</tr>
<tr>
<td>Amplitude</td>
<td></td>
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</table>

Δ systolic/  
| systolic    | -5 ± 15   | +8 ± 14  | -9 ± 13  |
| diastolic   | -9 ± 10   | +8 ± 12  | -0 ± 8   |
| mean/       | -13 ± 11  | +7 ± 12  | -1 ± 9   |
| Mittel      |           |         |          |         |
| pulse/      | +3 ± 12   | -0 ± 9   | -0 ± 9   |
| Amplitude   |           |         |          |         |
Ohmeda devices had a somewhat slower pressure response and this caused overshoot of the pressure pulsation over and beyond what occurs physiologically. In addition, Ohmeda cuff designs changed frequently. Their original white “paper” cuffs had good response and good sensitivity. Their black plastic cuffs that followed soon were easier to apply but had slow dynamic response. They were also quite position sensitive. The recent Ohmeda gray cuffs have good dynamic response in combination with the improved servo valve in the front-end of the Model 2300e, but still are position sensitive. The TNO velcro cuff design has remained stable since 1984. Its sensitivity is less but dynamic response is better and position sensitivity is acceptable and usually is not noticed.

For readings to be correct it is necessary that at least 30 beats pass between subsequent Physioceals and, for each Physioical, that the steady levels step up at most two levels from the initial level (Fig. 5).

Cold fingers has been described as a problem situation (16). The above criteria apply also to this situation. Often, however, cold fingers are secondary to vasoconstriction and follow arterial contraction rather then lead it. Warming of the hand may help reverse the condition as the subject then becomes more comfortable. In cooled patients on total heart-lung bypass, but anesthetized, no contraction seems to take place.

Changes in hematocrit and oxygen tension change the color and absorption coefficient of the blood. This is compensated by Physioical.

**Quality control points**

Finapres accuracy can be improved by adhering to certain simple control points. The percentage of nonanesthetized people on which Finapres works immediately can be increased to virtually 100% by taking simple measures of comfort. If a good reading is not obtained immediately just let the device continue for a minute or two. Divert the attention of the subject. If a good reading is still not obtained, try a thumb, or another finger, or the other hand. To obtain best accuracy and highest yield with either device, adhere to the following:

**Fig. 5** Physioical is a small expert system that gauges the finger arteries under the cuff. It demonstrates its opinion in its outward behavior. Five different Physioceals are shown. The quality of the pressure recording is judged “excellent” at the top Physioical, descending via “good” and “probably adequate” to “insufficient” and “bad” in the lowest trace.

1) Awake subjects should be comfortable. A reasonable room temperature, no chilly drafts, a comforting word.

2) Select a proper cuff. Do not use Ohmeda's black cuffs; their new gray ones are better. Select the correct size according to the Finapres manual.

3) Fit the cuff carefully, as shown diagrammatically on the patient's hand box. Make the fit tight. The left or right middle finger, mid-phalanx, is often preferred.

4) Elderly patients should be warned that interruptions in the pulse can be felt that are due to the device's PhysioCal.

5) Start Finapres but do not take readings until at least 30 beats pass between PhysioCals and the PhysioCal staircase steps up at most twice.

6) Do not switch PhysioCal off until the above situation has been reached, and never switch it off for long periods.

7) If finger pressure rises slowly (taking more than 0.1 s to systolic) there may be proximal lesions or pinch-off. Try the other hand.

8) If, after a period with PhysioCal off, it is turned back on, observe that no pressure level shift occurred between the 30 s just before and just after the PhysioCal. There is no established period the can be considered safe with PhysioCal off. In some subjects pressure tracking is stable for an hour, in others only a few minutes.

**Applications**

The useful application of Finapres is primarily when blood pressure is highly variable or when fast blood pressure changes are induced and must be recorded continuously. Finapres is quite resistant to artifact (10). When intraarterial monitoring is considered unethical, or unavailable, or cannot be repeated as often as needed, or is too expensive, the use of Finapres is also indicated.

With some 300 papers found in a recent (mid 1995) search, Finapres has found many applications. A printed copy of this list is available from the author.

**Conclusion**

A remarkable number of applications has been found for Peñáz's original invention, given the limitations of the peripheral measurement site. For the future, clearly, substantially improved accuracy and precision of the finger pressure compared to intrabrachial pressure can be obtained with simple measures. This improves tracking of blood pressure changes and the diagnostic usefulness of finger pressure measurements.

**References**


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