Non-invasive hemodynamic measurements early in pregnancy
Rang, S.

Citation for published version (APA):
Comparison of Portapres® with Standard Sphygmomanometry in Pregnancy

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Abstract

**Background:** Continuous beat-to-beat noninvasive blood pressure (BP) measurement is possible with Portapres®. It constructs finger arterial waveforms beat-to-beat. Dedicated software is used to analyze the arterial waveforms. A new technique has been developed to reconstruct brachial intraarterial pressure that uses return to flow (RTF). This method has been validated against invasive intraarterial measurements in nonpregnant individuals.

**Objectives:** To validate Portapres in normal and preeclamptic pregnant women against standard anaeroid sphygmomanometry according to Riva-Rocci-Korotkoff (RRK).

**Methods:** In 30 normotensive (10 in each trimester) and 20 preeclamptic women, two trained observers blinded from each other’s results took BP measurements with a standard sphygmomanometer. These measurements were compared with sequential same-arm averaged measurements obtained during 30 sec by Portapres, following protocols from the Association for the advancement of Medical Instrumentation (AAMI, mean accepted difference ≤5 mmHg, SD ≤8) and British Hypertension Society (BHS, gradings A down to D).

**Results:** A total of 150 measurement pairs were analyzed. Cumulative percentages of absolute pressure differences for all women (BHS) and mean pressure differences (SD) for different trimesters and preeclampsia (AAMI) between sphygmomanometry and Portapres were calculated. Overall, mean difference (SD) for systolic BP was 5(SD 8) and for diastolic BP was –3(SD 8), although analysis of variance revealed a significant effect for preeclampsia on diastolic differences between the two methods of BP measurement (p<0.001).

**Conclusions:** Portapres with RTF, developed to equal intraarterial brachial pressure, compares reasonably well to RRK and overall meets the criteria set by the AAMI. According to the BHS, Portapres receives a B-grading for diastolic BP and a C-grading for systolic BP. As Portapres measures BP and calculates cardiac output continuously and noninvasively, it would appear worthwhile to further evaluate this device in pathological pregnancies.
Portapres vs. sphygmomanometer

Introduction

Intraarterial blood pressure (BP) measurement is considered to be the most accurate way to measure BP continuously. Because of its invasiveness and risk for embolism and infection, it is less suitable for repeated use during clinical practice in pregnancy. However, beat-to-beat BP measurement is possible with Portapres®, which estimates BP on a continuous and noninvasive basis at the finger. Portapres [1,2] is the portable version of Finapres [3]. Additional algorithms have been developed to calculate cardiac output on the basis of the finger arterial waveform.

Portapres has been validated against invasive measurements in previous studies with nonpregnant individuals. The BP obtained from the finger corresponded closely to brachial intraarterial measurements [4-8]. Although Portapres has been shown to perform accurately during different physiological circumstances, Portapres should not be applied to pregnant women without proper validation. In situations of high flow, like normal pregnancy or narrow peripheral arteries, as in preeclampsia, the pressure gradient between brachial artery and finger artery, which is normally negligible, might be considerably altered [9-11].

Measuring BP by standard Riva-Rocci-Korotkoff (RRK), sphygmomanometry is a routine of physical examination during pregnancy and crucial for obstetrical decision making [12]. However, RRK measurements have their shortcomings, related to intra-observer variability and limitations in numbers of measurements that can be taken conveniently [13-17]. Although independent associations between automated BP measurement and birthweight, as well as adverse maternal outcome, have been documented [18,19], most literature on obstetrical outcome is based on RRK. Therefore, measurements recorded with automated BP monitors, such as the Oxford ABPM, the Dinamap 1846SX and Spacelabs 90207 [20], have been compared with RRK measurements. However, although some automated monitors perform adequately in comparison with standard sphygmomanometry [20], they still determine BP on an intermittent base. We therefore evaluated Portapres against the clinical gold standard (i.e., RRK measurements). As a first step in this process, this study was designed to determine differences in BP levels at rest between Portapres and standard sphygmomanometry during different stages of (physiological and pathological) pregnancy using both the British Hypertension Society (BHS) and the Association for the Advancement of Medical Instrumentation (AAMI) protocols for the validation of BP measuring devices.

Since possible pressure differences between brachial artery and finger artery can be corrected with return to flow (RTF) correction (see METHODS), we compared the reconstructed brachial artery pressure (Portapres with RTF) from finger arterial pressure as well as the nonreconstructed (Portapres) with RRK (see METHODS) [8].
Methods

Patients
Portapres was studied in a group of 50 pregnant women according to the device validation protocol of the BHS [21] and the recommendations of AAMI [22]. Following these protocols at least 30 subjects should be included into a study to obtain a heterogeneous population and to reach sufficient statistical power. Therefore, 30 pregnant women were asked to participate in the study, of whom 10 women were in their first (until 13 weeks gestation), 10 in their second trimester (13 - 23 weeks gestation), and 10 in their third trimester of pregnancy. Additionally, 20 women suffering from preeclampsia (diastolic BP ≥ 90 mmHg, proteinuria ≥ 0,3 g/24hr) were selected for the study. Age, weight, height, upper arm circumference, and BP range were recorded from all participants. All patients were recruited from the Department of Obstetrics in the Academical Medical Centre, Amsterdam, The Netherlands. Approval for the use of Portapres in preeclamptic and normal pregnancy was obtained from the Medical Ethics Committee and informed consent was obtained from all subjects.

Study device.
Portapres (model 2) is the portable version of Finapres (FINger Arterial PRESsure), developed by the TNO-group Bio-Medical Instrumentation (BMI) in the Academical Medical Centre in Amsterdam, The Netherlands. Portapres uses the methodology of Penaz [23] and the physiocal criteria of Wesseling [24] to measure BP continuously and noninvasively. This technique depends on circumferential pressure applied by a finger cuff that is varied to maintain constant digital arterial size. Digital arterial size is determined photoplethysmographycally. Under these conditions, the external cuff pressure equals the internal arterial pressure. A rapidly responding servomechanism constantly adjusts finger cuff pressure to maintain zero transmural arterial pressure. Heart rate and systolic, mean, and diastolic arterial pressures are derived from the stored pressure trace [25]. The exact principle of the device has been described elsewhere [5,23,24]. Pulse wave distortion is corrected with a generalised waveform filter [26]. Of importance for this study is that possible pressure gradients are corrected with RTF measurements. Every time an upper arm cuff is inflated above brachial arterial systolic pressure and subsequently is slowly deflated, RTF detects systolic BP by registering the upper arm cuff pressure at the moment that the first BP pulsation is detected in the finger cuff [8]. In this way, individual level correction is made.

Study Protocol.
The AAMI recommendations and the BHS protocol were not designed to compare devices that measure indirect intraarterial BP values on a continuous beat-to-beat basis with intermittent auscultatory indirect sphygmonanometry. We therefore chose to take the average of 30 sec of a stable signal obtained by Portapres as the BP level to com-
Portapres vs. sphygmomanometer

pares with the preceding and following (BHS) or following (AAMI) RRK measurement. In that way, we could follow the guidelines of AAMI and BHS as closely as possible. Training of observers was done before the study was started according to the BHS protocol. Auscultatory RRK measurements with a standard sphygmomanometer (Maxi Stabil 3, Speidel & Keller, Germany) were used as the standard. We did not use the mercury standard because this is no longer used in clinical practice in Holland. During the measurements, the observers recorded the Korotkoff Sound I for systolic BP and the Korotkoff sound V for diastolic BP. The sphygmomanometer used in this study was calibrated before and after the study and there was no correction necessary. The measurements were performed in a comfortable (23°C) and quiet room. Cuffs in the appropriate size for both the finger and the arm were selected. The finger cuff was attached to the third digit of the left hand. Portapres registration and the RRK measurement were performed on the same arm. Finger BP and upper arm cuff pressure were digitized at 100 Hz and stored. Since Portapres measures continuously and the signal is interrupted when an upper arm cuff is inflated, sequential measurements were obligatory. Patients were measured in the supine position and were asked neither to speak nor move during the procedure. Women in their third trimester of pregnancy were put in left lateral tilt to avoid aortic-caval compression. After a resting period of at least 5 min, Portapres was connected to the subject and BP was determined after a stable signal was found. The cuff was inflated up to 20 mmHg above systolic pressure and during manual deflating (speed: 2-3 mmHg/heartbeat) of the cuff, RTF detected the systolic BP. The patient was labelled for analysis either normotensive or hypertensive (diastolic BP ≥ 90 mm Hg) on basis of clinically taken auscultatory BP measurements with a standard sphygmomanometer. All hypertensive women had significant proteinuria (≥ 0.3 g /24 hr or 2+ on dipstick) and were therefore preeclamptic according to ISSHP criteria.

The first two trained observers performed an RRK measurement, then Portapres registered BP for approximately 2 min, and subsequently, the observers (who were blinded for each other and from the Portapres device) determined BP by sphygmomanometry. Then, Portapres registered again for 2 min and so on. In total, the observers as well as Portapres measured six times. RTF registrated systolic BP every time the arm cuff was inflated.

Statistics.

Two separate analyses were performed according to either the AAMI or the BHS.

Association for the Advancement of Medical Instrumentation

The last three of the six recordings from both Portapres and the observers were used for data analysis. Each single measurement taken by both observers was averaged to render three RRK values for systolic, diastolic, and mean arterial pressure for each single patient. Each Portapres reading was the average of a measurement period of 30 sec before inflating the arm cuff to measure BP by the RRK method. Then, the three RRK
values were averaged and compared to the averaged values of three Portapres readings. The mean difference and standard deviation of the mean difference between observers and Portapres was calculated. Bland-Altman plots [27] were constructed for the total of the 150 readings, separately for systolic and diastolic pressures (Figure 1A-D). The observers were compared similarly in the BHS and AAMI analysis.

**British Hypertension Society**

Analysis was done separately for observer 1 and 2, giving a total of 150 pairs of readings for each observer. Differences were calculated for both the RRK measurement preceding the Portapres reading and the RRK measurement after the Portapres registration. The BHS protocol recommends selection of results with the smallest differences. The study device was then graded from A down to D based on the cumulative percentage of all individual differences ≤ 5, ≤ 10, and ≤ 15 mmHg. The results are documented in Table 2. For the final grading, the results between Portapres and the observer rendering the smallest difference were selected for both diastolic and systolic pressure.

**Table 1. Baseline Characteristics for All 50 Subjects**

<table>
<thead>
<tr>
<th></th>
<th>Range</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>15–43</td>
<td>29 (6)</td>
</tr>
<tr>
<td>Weight</td>
<td>50–103</td>
<td>68 (13)</td>
</tr>
<tr>
<td>Height</td>
<td>150–179</td>
<td>168 (7)</td>
</tr>
<tr>
<td>Arm circumference (cm)</td>
<td>21–39</td>
<td>28 (4)</td>
</tr>
<tr>
<td>Blood pressure (mm Hg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Tri (n = 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys</td>
<td>103–149</td>
<td>117 (12)</td>
</tr>
<tr>
<td>Dias</td>
<td>62–82</td>
<td>71 (6)</td>
</tr>
<tr>
<td>2nd Tri (n = 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys</td>
<td>92–129</td>
<td>110 (13)</td>
</tr>
<tr>
<td>Dias</td>
<td>55–82</td>
<td>67 (8)</td>
</tr>
<tr>
<td>3rd Tri (n = 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys</td>
<td>92–128</td>
<td>112 (11)</td>
</tr>
<tr>
<td>Dias</td>
<td>51–89</td>
<td>74 (12)</td>
</tr>
<tr>
<td>Hypertensive (n = 20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys</td>
<td>122–181</td>
<td>145 (16)</td>
</tr>
<tr>
<td>Dias</td>
<td>77–113</td>
<td>97 (10)</td>
</tr>
<tr>
<td>All women (n = 50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys</td>
<td>92–181</td>
<td>126 (21)</td>
</tr>
<tr>
<td>Dias</td>
<td>51–113</td>
<td>81 (16)</td>
</tr>
</tbody>
</table>

SD = standard deviation
*Measured by RRK, average of two observers

**Results**

The baseline characteristics of all 50 patients are listed in Table 1. Of the preeclamptic patients, 16 women used antihypertensive medication: α-methyl-DOPA (13), labetolol (2), nifedipine (3), Ketensin i.v. (1) or combination (3). Portapres produced technically acceptable registrations during all measurements.
Observer agreement
For systolic pressure, the observers agreed within 5 mmHg for 99% and within 10 mmHg for 100% of their simultaneous auscultations. For diastolic pressure, these percentages were 98% and 100%, respectively (see Table 2). These values fulfill the criteria of the AAMI and the BHS.
Differences Portapres® vs. Standard Sphygmomanometry

Cumulative percentages of pressure differences ≤ 5, ≤ 10, and ≤15 mmHg between observers and Portapres are presented in Table 2. The grading criteria of the BHS are shown in the upper part of Table 2. According to these criteria, Portapres with RTF achieved a B-grading for the comparison of diastolic measurements and a C-grading for the comparison of systolic measurements. Portapres achieved a D-grading for the comparison of systolic and diastolic measurements without RTF.

The last column in Table 2 presents mean pressure differences and SD between Portapres and observers. The AAMI criteria (mean pressure difference no more than 5 mmHg, and SD no more than 8mmHg) were reached for both diastolic and systolic pressure measurements with RTF.

Mean pressure differences (+SD) were also calculated for first, second, and third trimester of pregnancy separately as well as for hypertensive pregnancy. The results are shown in Table 3.

![Figure1](image-url)

**Figure1.** Bland-Altman plots of pressure difference (Portapres minus Observers) against observed mean pressure (observers plus Portapres, divided by two) in 50 pregnant women. Lines are drawn for mean pressure and +/- 2 SD. Plots are constructed for Systole (A/B) Diastole (C/D) separately for readings with RTF (A/C) and without RTF (B/D).
Figure 1 shows the Bland-Altman plots of the pressure differences (device minus observers) against the mean of the observer and Portapres readings for both systolic and diastolic pressures with and without RTF. Bland-Altman plots suggest an effect of average BP on the BP differences. Therefore, we additionally performed an analysis of variance and multiple comparison tests (Scheffe) to reveal factors influencing the measured differences. A significant effect for preeclampsia on diastolic differences (p<0.001) was found. If the patient’s average diastolic BP was entered in the analysis as a covariate, the effect of preeclampsia could be explained by BP alone (p<0.001). Trimester (i.e. gestational age) unexpectedly influenced systolic BP differences (p=0.004) independent of average systolic or diastolic BP. The order of the different BP readings had no effect on systolic or diastolic differences in repeated measurement analysis.

Table 3. Mean Pressure Differences (SD) in mm Hg Between Two Observers by Sphygmomanometry and Portapres (± RTF) in First Trimester, Second Trimester, Third Trimester and Hypertensive Women

<table>
<thead>
<tr>
<th></th>
<th>1st Trimester (n=10)</th>
<th>2nd Trimester (n=10)</th>
<th>3rd Trimester (n=10)</th>
<th>Hypertensive (n=20)</th>
<th>All women (n=50)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Systolic pressure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portapres +RTF</td>
<td>11 (8)</td>
<td>9 (6)</td>
<td>2 (6)</td>
<td>3 (8)</td>
<td>5 (8)</td>
</tr>
<tr>
<td>Portapres-RTF</td>
<td>6 (13)</td>
<td>0.5 (9)</td>
<td>-7 (7)</td>
<td>-4 (11)</td>
<td>-1 (7)</td>
</tr>
<tr>
<td><strong>Diastolic pressure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portapres + RTF</td>
<td>1 (7)</td>
<td>2 (7)</td>
<td>-1 (7)</td>
<td>-8 (6)</td>
<td>-3 (8)</td>
</tr>
<tr>
<td>Portapres-RTF</td>
<td>-3 (5)</td>
<td>-6 (8)</td>
<td>-10 (6)</td>
<td>-15 (7)</td>
<td>-9 (8)</td>
</tr>
<tr>
<td><strong>Mean arterial pressure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portapres + RTF</td>
<td>8 (5)</td>
<td>6 (5)</td>
<td>2 (5)</td>
<td>0.6 (5)</td>
<td>4 (6)</td>
</tr>
<tr>
<td>Portapres-RTF</td>
<td>4 (6)</td>
<td>-1 (6)</td>
<td>-7 (5)</td>
<td>-7 (8)</td>
<td>-3 (8)</td>
</tr>
</tbody>
</table>

**Discussion**

As far as we are aware, this is the first study comparing noninvasively measured beat-to-beat finger BP readings with indirect standard sphygmomanometry in normal and preeclamptic pregnant women. We realize that comparison of Portapres with direct intraarterial pressure measurements is to be preferred over indirect measurements. However, if Portapres is to be used in clinical practice, it must be compared to the clinical gold standard (i.e., standard sphygmomanometry). A next step in the validation process should be comparison with intraarterial readings. Wilkes et al.[28] and Porter et al.[29] compared a Finapres (an earlier version of Portapres without RTF) with intraarterial pressure in pregnant women during labor or caesarean section. Both found that Finapres underestimates intraarterial systolic BP. Only Wilkes et al. found Finapres to
underestimate diastolic BP. However, most data on BP in pregnant women refer to standard sphygmomanometry. In a previous study by Brown et al. [30], standard sphygmomanometry was compared to direct brachial intraarterial BP. In this study, it was shown that standard sphygmomanometry underestimates brachial arterial systolic BP by an average of 11 mmHg and overestimates diastolic pressure by 4 mmHg. Since Portapres with RTF aims to reflect brachial intraarterial pressure [8], one would expect it to overestimate systolic pressure and underestimate diastolic pressure measured by standard sphygmomanometry. In our hands, Portapres with RTF indeed overestimates systolic pressure (by 5 mmHg, SD 7) and underestimates diastolic pressure (by 3 mmHg, SD 8) as measured by standard sphygmomanometry. This is in line with the results of Brown et al.[30] and suggests that BP determined by Portapres with RTF might be more comparable to direct intraarterial BP than standard sphygmomanometry. So, Portapres appears to give an accurate estimation of intraarterial brachial BP in pregnancy, although direct evidence for this must be obtained in future studies.

We preferred sequential same-arm measurements over simultaneous measurements at the opposite arm with the inherent BP difference between the right and left arm. Due to analysis of RTF, we were forced to inflate an arm cuff at the same arm (see METHODS). We would have had to double the number of inflations if we had chosen for opposite-arm measurements. This we considered to be too inconvenient for the patients under study.

The BP differences between both observers fulfilled amply both the AAMI and BHS criteria and could therefore be used in comparison with the study device. According to the AAMI criteria, Portapres in combination with RTF estimates brachial artery BP with sufficient accuracy (maximal difference 5 mmHg, SD 8). For diastolic BP, Portapres with RTF obtained a BHS B-grading and for systolic pressure, a C-grading. Portapres, in combination with RTF, measures diastolic BP most accurately and compares favorably to other automated ABP-monitors [20]. However, this holds for overall performance taken all pregnant women. In different trimesters or preeclamptics alone, performance differs and does not always meet criteria set by the AAMI (see Table 1). This can be suspected when looking at the Bland-Altman plots. Analysis of variance indeed showed differences in device comparison between first trimester women compared to the third trimester women for systolic BP and between first and second trimester women compared to preeclamptic women for diastolic BP (Scheffe multiple comparison). This could be due to the aforementioned dynamic changes throughout pregnancy in blood flow and/or vascular resistance. In preeclampsia, vascular resistance and blood flow are seriously affected. In addition, antihypertensive medication influences both parameters. The balance of all these effects on the measurements with Portapres can only be estimated by the reported differences. Further evaluation is mandatory because of the small separate groups for each trimester. We are not aware of studies comparing direct with indirect methods in different trimesters of pregnancy. We
did not perform a separate analysis for differences between preeclamptic women with or without medication in view of the small number of women without antihypertensives. In conclusion, Portapres with RTF gives an accurate estimation of diastolic BP in pregnancy measured by standard sphygmomanometry. Portapres alone does not fulfill the criteria; however, after RTF correction, the performance improved to levels acceptable according to AAMI criteria. The BHS criteria were met for diastolic BP. Although Portapres almost received a B-grading, failing only 2% on the differences of < 10 mmHg (Table 2), a C-grading was achieved for systolic BP. Strictly speaking, the BHS prescribes that it is therefore not recommended for clinical use. Further evaluation is needed to explain differences in various trimesters of pregnancy and preeclampsia. Whether other features of this device (e.g., cardiac output estimation) can be used in pregnancy also needs speaking evaluation in future research. As to a possible conflict of interest, we would like to stress that Portapres needed to be validated independently. This was why this validation was not performed by the TNO/BMI staff. Neither the first author or the corresponding author were involved in (or commercially linked to) TNO/BMI. The Portapres device was the property of the department of obstetrics. Only one of the authors (Jeroen van Goudoever) is an employee of TNO/BMI. He offered free technical advice and could not influence data obtained during the study. Data were not discussed until all statistical analyses were completed. All data were analyzed by the first author and the corresponding author.
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