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Blood Pressure Measurement in Pregnancy – Interarm Differences and The Necessity of Multiple Consecutive Measurements

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ABSTRACT

Objective: To investigate multiple blood pressure measurements and interarm differences in a pregnant population.

Methods: Pregnant women attending routine antenatal ultrasound scans in gestational weeks 11-13 or week 20 had three consecutive blood pressure measurements on each arm conducted according to international guidelines. Mean and mean difference between the 1st measurement (BP-A) and 2nd + 3rd measurements combined (BP-B) as well as between right and left arm, respectively, were calculated and compared by paired t-test. Bland-Altman plots illustrate means and mean-differences of systolic and diastolic pressure between BP-A and BP-B.

Results: One-hundred women were included. Mean systolic, diastolic and arterial blood pressure for BP-A were 112.1 mmHg, 70.6 mmHg and 84.4 mmHg, respectively, while mean BP-B were 109.8 mmHg, 69.2 mmHg and 82.8 mmHg. Mean differences in systolic, diastolic and mean arterial pressure (MAP) between BP-A and BP-B were 2.5 mmHg ($P<0.001$, 95% Confidence interval (CI) 1.7;3.2), 1.5 mmHg ($P<0.001$, 95% CI 1.0;2.0) and 1.8 mmHg ($P<0.001$, 95% CI 1.4;2.2). Mean interarm differences in systolic, diastolic and MAP were 3.1 mmHg ($P<0.001$, 95% CI 1.9;4.3), 0.75 mmHg ($P=0.019$, 95%CI 0.1;1.4) and 2.4 mmHg ($P=0.01$, 95% CI 0.6;4.2).

Conclusion: In pregnancy, the first blood pressure measurement of three consecutive is significantly higher than the following two. Blood pressure on the right arm is significantly higher compared to the left arm. International guidelines on blood pressure measurements should apply to pregnant women.

Keywords: Algorithms, blood pressure monitoring, preeclampsia, pregnancy.

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INTRODUCTION

During pregnancy, the cardiovascular system undergoes substantial hemodynamic changes including increased cardiac output, increased heart rate, reduced systemic peripheral resistance and changes in arterial blood pressure, in order to ensure adequate fetal growth and development (1)(2). If these adaptations are inadequate, it may lead to adverse pregnancy outcomes, e.g. hypertensive disorders (3). Measuring blood pressure is a cornerstone in antenatal care worldwide, and antenatal care guidelines recommend blood pressure measurement at each routine visit during pregnancy to screen for hypertensive disorders (4)(5). Increasingly, blood pressure in early pregnancy is also used in algorithms along with risk factors such as maternal age and biomarkers to predict risk of preeclampsia later in pregnancy (6). Correct blood pressure measurement is thus pivotal.

International blood pressure monitoring guidelines and antenatal care guidelines have detailed recommendations on how to perform blood pressure measurements but are based on studies of non-pregnant populations (4) (5)(7)(8). This, combined with the adaptations in the cardiovascular system during pregnancy, makes the accuracy of blood pressure measurement in early pregnancy dubious (9)(10). It is important that blood pressure measurements in early pregnancy is accurate, as overestimation could lead to unnecessary, costly examinations and underestimation could lead to uncontrolled hypertension (11).

The main objective of this study is to investigate two aspects of blood pressure measurement among pregnant women from 11- 21 weeks of gestation;

1: The necessity of multiple consecutive measurements

2: Interarm-differences in blood pressure.

MATERIALS AND METHODS

Study population

Women attending routine nuchal translucency scan at gestational age (GA) 11-13 weeks or mid-pregnancy scan at GA 20 weeks from July 1st to July 29th 2016 at the outpatient antenatal clinic at the Department of Obstetrics, Rigshospitalet were invited to participate. There were no exclusion criteria. A list of demographics was filled out by the participants themselves.

Measurement of blood pressure

The measurement procedure followed international guidelines from European society of hypertension (ESH)(12), Association for Advancement of Medical Instrumentation (AAMI)(13) and the Danish hypertension society (DAHS)(7).

After the ultrasound scan, which required 15-20 minutes of rest, the women were guided to a shielded, calm area in the waiting room to await the measurements. The participants were seated in a chair with bag rest, with both feet on the ground and arms supported at heart level whilst a short presentation of the study was given. Following this, the circumference of the upper mid-arm was noted, and appropriate cuff-size chosen. Available cuff-sizes were normal adult: M = 22-32 cm and L-XL = 32-52 cm. After having been sitting for five minutes the participants had their blood pressure measured three times with 10 seconds intervals on each arm by a trained staff-member while instructed not to speak.

Device

Blood pressure measurements were conducted using the semiautomatic, validated device “Microlife Vital Sign alert (VSA)” which is based on an internal algorithm identical to the “blood pressure 3AS1-2”; this device has been validated for use in pregnancy including hypotensive states and hypertensive disorders of pregnancy(14) (13).

Statistical analysis

No power-calculations were done. All calculations were performed using R Studio version 1.1.463 (© 2009-2018 R Studio, Inc. 250 Northern Ave, Boston, MA 02210 844-448-1212). Mean systolic, diastolic and mean arterial pressure (MAP) were calculated for the 1st (BP-A) measurement as well as for the 2nd and 3rd measurements combined (BP-B). The 2nd and 3rd measurements were combined to clearly elucidate whether the typical clinical conduct with only one BP-measurement is sufficient for diagnosing and treating hypertensive disorders of pregnancy. Mean systolic, diastolic and MAP were calculated for right and left arm, respectively. MAP was calculated as ((2x diastolic) + systolic)/3. The results were normally distributed and mean differences of systolic, diastolic and MAP were compared by a paired t-test. A *P* value of 0.05 was considered significant and corresponding 95% confidence intervals were reported (95% CI). Systolic and diastolic differences were plotted in Bland-Altman plots.

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Ethical approval

All participants provided informed consent. The study was exempted from ethical approval by the Regional Ethical Committee for the Capital Region (Protocol No. H-16022273).

RESULTS

A total of 100 women were recruited for the study, resulting in 600 measurements. If a measurement deviated more than 15 mmHg from the other measurements on the same arm, it was considered an error: BP is expected not to deviate more than 10 mmHg between consecutive measurements if the equipment is validated and if measurement procedure is consistent (15). All measurements from that series were therefore omitted: seventy-eight measurements (6%) of both systolic and diastolic pressure being omitted in total. This 15 mmHg limit was decided after data collection since the deviations were not expected beforehand. Two women were excluded because of deviations greater than 15 mmHg on both arms (N=1) and because of less than two measurements in total (N=1). The demographics of women whose measurements were excluded were comparable in cuff-size and trimester to the women with included data.

The demographics of the population are shown in table 1. Mean age was 31 years. Mean BMI was 23.7 Kg/m2. Mean arm circumference was 25.8 cm fitting a medium size-cuff in 97% of the women. Three women used L-XL cuff. Of the included participants 98 women were normotensive and two women fulfilled criteria for hypertension.

Multiple measurements

BP-A and BP-B mean values are listed in table 2 while mean differences in blood pressure between BP-A and BP-B are listed in table 3 with corresponding p-values and 95% confidence intervals. The mean systolic pressure was 112.1 mmHg for BP-A and 109.7 mmHg for BP-B. The mean difference was 2.5 mmHg (P<0.001; 95% CI 1.7; 3.2). The mean diastolic pressure was 70.6 mmHg for BP-A and 69.3 mmHg for BP-B. Mean diastolic difference was 1.5 mmHg (P<0.001; 95% CI 1.0; 2.0). MAP was 84.4 mmHg for BP-A and 82.8 mmHg for BP-B. Mean difference in MAP was 1.8 mmHg (P<0.001, 95% CI 1.4; 2.2). Two Bland-Altman plots (figure 1 and 2) illustrate the differences in systolic and diastolic pressures between BP-A and BP-B.

Interarm differences

Mean values of blood pressure on right and left arm are listed in table 2 and mean differences in blood pressure between right and left arm are listed in table 3. The mean systolic pressure was 111.9 mmHg on the right arm and 108.9 mmHg on the left arm. Mean difference in systolic pressure was 3.1 mmHg (P<0.001, 95% CI 1.9; 4.3). The mean diastolic pressure was 70.0 mmHg on the right arm and 69.3 mmHg on the left arm. Mean difference in diastolic pressure was 0.75 mmHg (P=0.019, 95% CI 0.1; 1.4). MAP was 83.9 mmHg on the right arm and 81.5 mmHg on the left arm yielding a mean difference of 2.4 mmHg (P=0.01, 95% CI 0.6; 4.2).

		Mean	Range	Minimum	Max	Std. Deviation
1	**Age (years)**	31.4	23	22	45	4.4
2	**Weight (kg)**	67.4	86.0	45.0	131.0	11.5
3	**Arm circumference (cm)**	25.8	14.0	21.0	35.0	2.6
4	**Height (cm)**	168.9	32.0	152.0	184.0	6.4
5	**BMI (kg/m2)**	23.6	29.5	16.9	46.4	4.0
6	**Systolic pressure**	111.4	44.4	93.7	141.5	10.1
7	**Diastolic pressure**	69.8	33.0	41.0	89.3	7.4
8	**Gestational age**	15.3	9.0	11.0	20.0	3.6

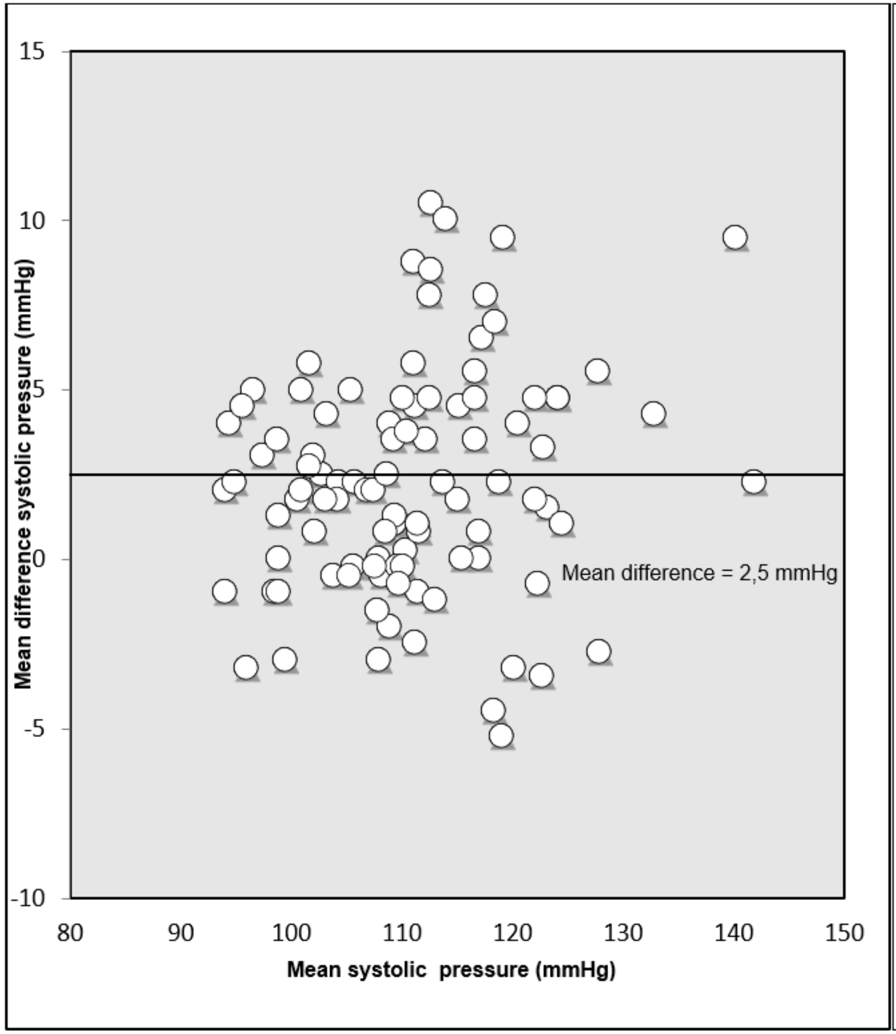
Table 1: Demographics of the study population

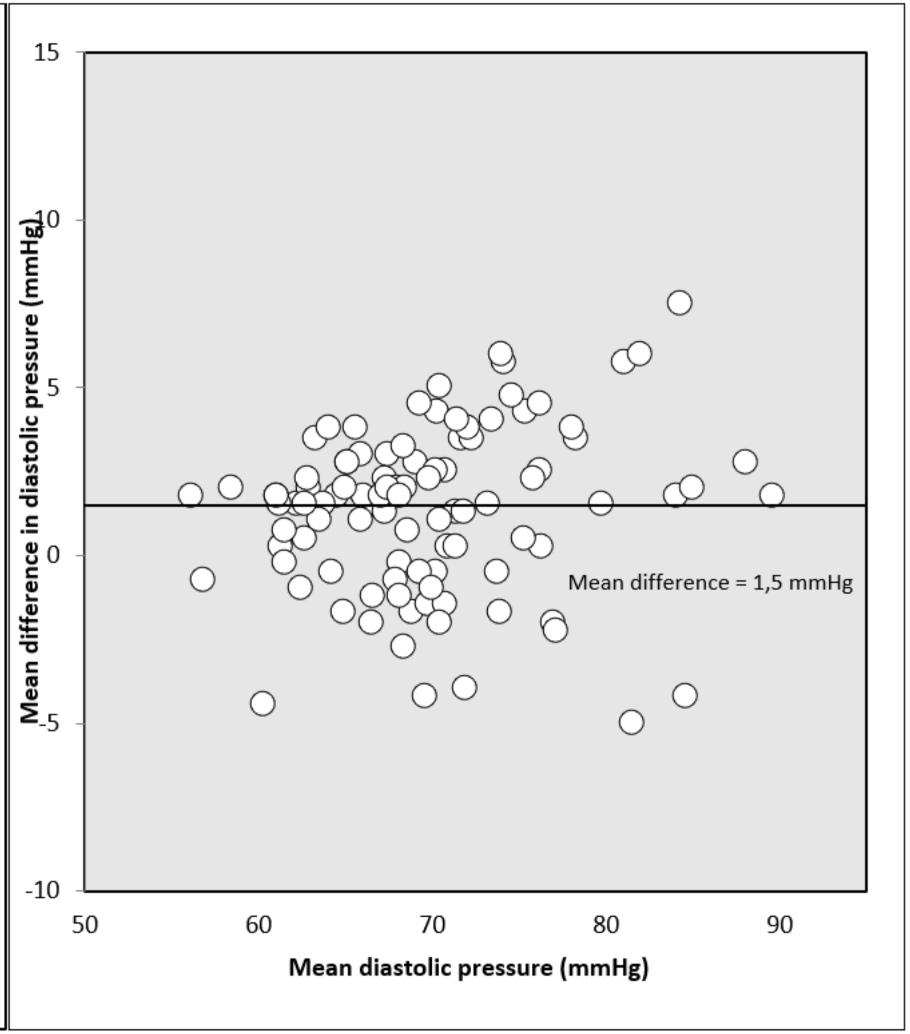
		Systolic BP, mean ± SD (mmHg)	Diastolic BP, mean ± SD (mmHg)	MAP, mean ± SD (mmHg)
1	**Measurement 1 (BP-A)**	112.1 ± 10.0	70.6 ± 7.3	84.4 ± 7.6
2	**Measurement 2**	111.0 ± 9.2	69.6 ± 7.0	83.4 ± 7.2
3	**Measurement 3**	108.5 ± 10.4	69.0 ± 6.5	82.2 ± 7.7
4	**Mean of 2nd and 3rd measurements (BP-B)**	109.7 ± 9.4	69.3 ± 6.7	82.8 ± 7.2
5	**Right arm**	111.9 ± 9.7	70.0 ± 6.8	83.9 ± 7.2
6	**Left arm**	108.9 ± 10.1	69.3 ± 7.2	81.5 ± 11.4

Table 2: Descriptive statistics of the systolic, diastolic and mean arterial pressure for the 1st, 2nd and 3rd measurements and for right and left arm, respectively. MAP = Mean arterial pressure.

		Mean Difference ± SD (mmHg)	P-value	95% CI
1	**Systolic difference BP-A vs BP-B**	2.5 ± 7.1	<0.001	1.7 - 3.2
3	**Diastolic difference BP-A vs BP-B**	1.5 ± 10.1	<0.001	1.0 - 2.0
5	**MAP difference BP-A vs BP-B**	1.8 ± 2.0	<0.001	1.4 - 2.2
7	**Systolic difference Right vs left**	3.1 ± 5.7	<0.001	1.9 - 4.3
8	**Diastolic difference Right vs left**	0.75 ± 3.0	0.019	0.1 - 1.4
9	**MAP difference Right versus left**	2.4 ± 3.1	0.01	0.6 - 4.2

Table 3: Mean-differences in systolic, diastolic and MAP between BP-A and BP-B as well as between right and left arm. CI = Confidence Interval.





Figures 1 and 2: Difference in mean systolic (left) and diastolic (right) pressure for the 100 patients, presented in two Bland Altman plots. X-axis shows the mean systolic or diastolic pressure for all three measurements on both right and left arms. Y-axis shows the mean difference between BP-A and BP-B from both arms. Mean of the mean differences between BP-A and BP-B is presented as a line.

DISCUSSION

The major findings of the study were, firstly, that the first of three consecutive measurements was significantly higher than the following two regarding both systolic, diastolic and MAP, and secondly, measurements from left and right arm differed significantly in pregnant women, with the greatest difference found in systolic pressure, where mean BP on the right arm was 3.1 mmHg higher than BP on the left arm. The differences were equally distributed in the observed measurements.

These two findings support findings from the non-pregnant population as well as findings in one study on measuring MAP for algorithms in early pregnancy (16) (17). Thus, general BP guidelines from ESH-, DAHS as well as earlier studies on the non-pregnant population recommend conducting at least two BP measurements until large differences are eliminated and initially conducting measurements on both arms and then choosing measurements from the arm with the highest BP (7) (8) (16). However, European recommendations on antenatal care do not describe more than one BP measurement as necessary, nor do current studies on antenatal care deem interarm differences necessary to take into account (18) (4) (5).

The results of this study confirm that recommendations on how to measure BP based on the normal population should also apply to pregnant women despite large changes in the hemodynamic system. The results also suggest that this procedure of conducting BP measurement should be part of antenatal care recommendations and daily obstetrical practice to ensure accurate measurements.

The absolute differences of 2.5 mmHg in consecutive measurements and 3.1 mmHg in interarm measurements are, however, small which combined with the participants being predominantly normotensive, make therapeutic consequences of the findings unlikely for the majority of pregnant women. However, blood pressure is increasingly being used as early risk prediction of hypertensive disorders of pregnancy including preeclampsia by algorithms (19) (6), and even small imprecisions will potentially miscategorise women to a higher or lower risk group resulting in inadequate preventive strategies. Our results therefore emphasize the necessity of strictly following guidelines when measuring blood pressure for use in algorithms. However, further investigation of the necessity of multiple measurements would be beneficial. It would be of interest to examine a larger cohort of pregnant women over time and in different stages of pregnancy to identify which women would be categorized differently by multiple BP measurements and explore potential clinical consequences hereof.

A strength to our study is the original and specific BP data collected in a pregnant population, that only few studies have investigated despite the known hemodynamic changes. All participants were recruited during daytime 8am-4pm which ensures that data is applicable to normal prenatal ambulatory hours despite known circadian variations in blood pressure(20). Some limitations are apparent: First, physiological short-term variability in BP could affect differences as small as the ones found in this study, as BP is known to fluctuate with breathing and heart-rate (21). Second, the population in this study represent pregnant women with higher socio-economic status and lower BMI than the average Danish pregnant woman due to the geographic uptake area of Rigshospitalet. A future, similar study done on a pregnant population with more obesity, higher occurrence of smokers, differing ethnicity or lower socio-economic status might find even more significant deviations in BP. This might also be the case, had the time interval between measurements been longer than 10 seconds – e.g. 1 minute as recommended by the ESH. The 10 seconds interval was chosen to make the measurement method easier to incorporate in the daily clinical routine in terms of time spent by staff on BP measuring. In hindsight it would have been truer to the aim of the study had the interval been more aligned to the ESH guideline. Third, the lack in systematics regarding which arm was measured upon first might have resulted in right-bias: by starting with the right arm more often, the time passing before measuring on the left arm might explain the difference found in BP. Future studies should take the order of the arms into account in the study design.

CONCLUSION

In summary, this study confirms that in pregnant women the first BP measurement of three consecutive is significantly higher than the two following. Furthermore, BP on the right arm is significantly higher than BP on the left arm. Finally, guidelines for BP measurements based on the normal population regarding number of measurements and choice of arm apply to pregnant women as well and should be part of antenatal care recommendations.

Conflict of interest: None
Author contributions: FFL and JAL planned the study. FFL collected the data, KH interpreted the data. KH conducted statistical analysis. KH wrote the initial draft of the manuscript with all authors contributing to and approving the final manuscript submitted.
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