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Blood pressure tracking during pregnancy and the risk of gestational hypertensive disorders: The Generation R Study

Romy Gaillard[1,2,3], Rachel Bakker[1,2], Sten P. Willemsen[4], Albert Hofman[2], Eric A.P. Steegers[5], and Vincent W.V. Jaddoe[1,2,3]*

[1]The Generation R Study Group, Erasmus Medical Center, PO Box 2040, 3000 CA Rotterdam, The Netherlands; [2]Department of Epidemiology, Erasmus Medical Center, The Netherlands; [3]Department of Paediatrics, Erasmus Medical Center, The Netherlands; [4]Department of Biostatistics, Erasmus Medical Center, The Netherlands; and [5]Department of Obstetrics and Gynaecology, Erasmus Medical Center, The Netherlands

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Aims Blood pressure tracking can be used to examine the predictability of future values by early measurements. In a population-based prospective cohort study, among 8482 pregnant women, we examined whether blood pressure in early pregnancy tracks to third trimester and whether this tracking is influenced by maternal characteristics and is associated with the risk of gestational hypertensive disorders.

Methods and results Blood pressure was measured in each trimester of pregnancy. Information about doctor-diagnosed pregnancy-induced hypertension and preeclampsia was obtained from medical records. Correlation coefficients between first and third trimester for systolic and diastolic blood pressure were 0.47 and 0.46, respectively. The odds ratio for staying in the highest tertile from first to third trimester for systolic blood pressure was 3.09 [95% confidence interval (CI): 2.73, 3.50] and for diastolic blood pressure 3.28 (95% CI: 2.90, 3.69). Blood pressure tracking coefficients were lower in younger, shorter, and non-European women and in women with higher gestational weight gain. Systolic and diastolic blood pressure changes from second to third trimester, but not from first to second trimester, were positively associated with the risks of pregnancy-induced hypertension and preeclampsia.

Conclusion Blood pressure tracks moderately during pregnancy and is influenced by maternal characteristics. Second to third trimester increases in systolic and diastolic blood pressure are associated with an increased risk of gestational hypertensive disorders.

Keywords Blood pressure • Pregnancy • Tracking • Preeclampsia • Cohort study

Introduction

Gestational hypertensive disorders complicate about 7% of all pregnancies and are associated with increased risks of both maternal and perinatal morbidity and mortality.[1,2] Blood pressure measurement is an important screening test used in obstetric care to detect or predict gestational hypertensive disorders.[2] However, the predictive accuracy of blood pressure measurement in early pregnancy still remains controversial.[3,4] A review among 34 studies showed that in first and second trimester, systolic and diastolic blood pressure predicted preeclampsia poorly.[3] This review compiled many studies with major methodological differences. The examined populations varied widely in their *a priori* risk of preeclampsia and blood pressure was measured at very different time-points in pregnancy. Also, many studies used different definitions of gestational hypertensive disorders.[5] Some studies suggested that blood pressure development differs between pregnancies uncomplicated and complicated by gestational hypertensive disorders and that small differences in blood pressure development may already occur in the first half of pregnancy.[4,6]

Tracking is used to describe the longitudinal development of a variable and focuses on the maintenance of one's relative position in a distribution of values over time.[7,8] Tracking can also be used to

* Corresponding author. Tel: +31 10 704 3405, Fax: +31 10 704 4645, Email: v.jaddoe@erasmusmc.nl

examine the predictability of future values by early measurements.[7,8] Examining tracking during pregnancy might give further insight in the predictive value of blood pressure measurement early in pregnancy. However, to the best of our knowledge, not much is known about blood pressure tracking during pregnancy.

Therefore, we examined in a population-based prospective cohort study among 8482 pregnant women, whether blood pressure in early pregnancy tracks to third trimester, and whether this tracking is influenced by maternal characteristics and is associated with the risk of gestational hypertensive disorders.

Methods

Study design

This study was embedded in the Generation R Study, a population-based prospective cohort study from early pregnancy onwards based in Rotterdam, the Netherlands.[9,10] The study has been approved by the Medical Ethical Committee of the Erasmus Medical Center in Rotterdam (MEC 198.782/2001/31). Written consent was obtained from all participating women. Assessments during pregnancy were planned in first, second, and third trimester. The individual timing of these assessments depended on the gestational age at enrolment. In total, 8880 women were enrolled during pregnancy. For the present study, we excluded women without any blood pressure measurement ($n = 18$). Also, we excluded women with pre-existent hypertension ($n = 146$) and pregnancies leading to foetal death ($n = 72$), induced abortion ($n = 27$), loss to follow-up ($n = 45$), and twin pregnancies ($n = 90$). Thus, the cohort for analysis comprised 8482 pregnant women (*Figure 1*).

Blood pressure

Blood pressure was measured with the validated Omron 907® automated digital oscillometric sphygmanometer (OMRON Healthcare Europe B.V. Hoofddorp, the Netherlands).[11] All participants were seated in upright position with back support, and were asked to relax for 5 min. A cuff was placed around the non-dominant upper arm, which was supported at the level of the heart, with the bladder midline over the brachial artery pulsation. In case of an upper arm exceeding 33 cm, a larger cuff (32–42 cm) was used. The mean value of 2 blood pressure readings over a 60 s interval was documented for each participant. In total, blood pressure was measured in 6379 women in first trimester (median 13.2 weeks of gestation, 95% range 9.8–17.6), in 7913 women in second trimester (median 20.4 weeks of gestation, range 18.5–23.6), and in 7995 women in third trimester (median 30.2 weeks of gestation, 95% range 28.4–32.9). For the analysis, 22 287 blood pressure measurements were available. Three, two, and one blood pressure measurements were available for 5857, 2091, and 534 women, respectively.

Pregnancy-induced hypertension and preeclampsia

Information on pregnancy complications was obtained from medical records. Women suspected of pregnancy complications based on

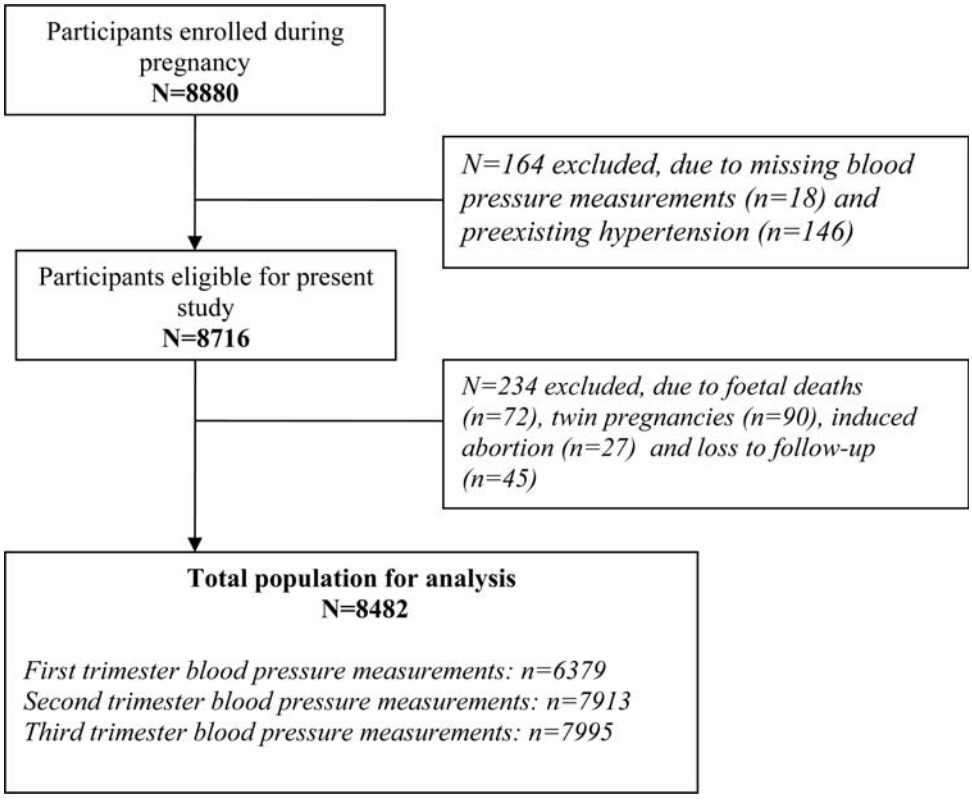

Figure 1 Flow chart of the participants.

these records were crosschecked with the original hospital charts. Details of these procedures have been described elsewhere.[12]

Briefly, the following criteria were used to identify women with pregnancy-induced hypertension: development of systolic blood pressure ≥140 mm Hg and/or diastolic blood pressure ≥90 mm Hg after 20 weeks of gestation in previously normotensive women. These criteria plus the presence of proteinuria (defined as two or more dipstick readings of 2+ or greater, one catheter sample reading of 1+ or greater, or a 24 h urine collection containing at least 300 mg of protein) were used to identify women with preeclampsia.[13] Information on pregnancy complications was available for 8236 women.

Covariates

Gestational age was established by foetal ultrasound examination during the first ultrasound visit.[10] Maternal age was assessed at enrolment. During visits in first, second, and third trimester, maternal anthropometrics were measured at one of the research centres. Height (cm) and weight (kg) were measured without shoes and heavy clothing and body mass index (kg/m^2) was calculated for each pregnancy period. We defined gestational weight gain as the difference between weight before pregnancy and weight in third trimester. Information on educational level, ethnicity, and parity was obtained at enrolment. Information about smoking, alcohol consumption, and caffeine intake was assessed by questionnaires in each trimester.[10]

Statistical analysis

First, we analysed the longitudinal systolic and diastolic blood pressure patterns in women with uncomplicated pregnancies and women with pregnancies complicated by hypertensive disorders using unbalanced repeated measurement regression models. These models take the correlation between repeated measurements of the same subject into account, and allow for incomplete outcome data.[14] Using fractional polynomials of gestational age, the best-fitting models were constructed. For this analysis, we categorized women in three categories: uncomplicated pregnancy, pregnancy-induced hypertension, and preeclampsia. The categories were included in these models as intercept and as an interaction term with gestational age.

To examine whether women maintain their position in the distribution of blood pressure (tracking), we estimated the Pearson's correlation coefficients and categorized systolic blood pressure, diastolic blood pressure, and mean arterial pressure in tertiles in first and third trimester. We used logistic regression models to calculate the odds ratio (OR) to remain in the same blood pressure tertile from first to third trimester. Next, we examined whether maternal characteristics influence blood pressure tracking. We categorized each maternal characteristic and for each category we estimated Pearson's correlation coefficients and blood pressure tracking coefficients using linear regression models. We further examined the associations of blood pressure change during pregnancy with the risks of pregnancy-induced hypertension and preeclampsia using multiple logistic regression models.

These models were adjusted for gestational age at intake, gestational age at each pregnancy period, maternal age, educational level, parity, ethnicity, pre-pregnancy body mass index, gestational weight gain, smoking habits, alcohol consumption, and caffeine intake. Missing data of the covariates were imputed using multiple imputation. The percentages of missing values within the population for analysis were lower than or equal to 15%, except for pre-pregnancy body mass index (19.4%) and gestational weight gain (23.1%). The repeated measurement analysis was performed using the Statistical Analysis System version 9.2 (SAS, Institute Inc., Gary, NC, USA), including the Proc Mixed module for unbalanced repeated measurements. All other analyses were performed using the Statistical Package of Social Sciences version 17.0 for Windows (SPSS Inc., Chicago, IL, USA). *P*-values are two-tailed. All presented confidence intervals (CIs) are calculated at the 95% level.

Results

Subject characteristics

Table 1 shows that, of all women, 306 women developed pregnancy-induced hypertension and 168 women developed preeclampsia. Women who developed pregnancy-induced hypertension and preeclampsia were more often nulliparous and had a higher pre-pregnancy body mass index. From first trimester onwards systolic blood pressure, diastolic blood pressure, and mean arterial pressure were higher for women who developed pregnancy-induced hypertension and preeclampsia in later pregnancy (*Table 2*).

Longitudinally measured blood pressure and gestational hypertensive disorders

Figure 2 shows the systolic and diastolic blood pressure development during pregnancy. Systolic blood pressure was higher from first trimester onward in women who developed pregnancy-induced hypertension and preeclampsia. The steepest increase in systolic blood pressure was observed in women who developed preeclampsia. Diastolic blood pressure showed a mid-pregnancy dip, with an increase thereafter in pregnant women without hypertensive disorders. In women with pregnancies complicated by pregnancy-induced hypertension and preeclampsia, a minor dip was observed in early pregnancy. Diastolic blood pressure was the highest throughout pregnancy for women who developed pregnancy-induced hypertension, but the steepest increase in diastolic blood pressure was observed for women who developed preeclampsia. The exact regression coefficients for gestational age-independent (intercept) and gestational age-dependent differences (interaction hypertensive complication and gestational age) are given in the Supplementary material online, *Table S1*.

Blood pressure tracking during pregnancy

Correlation coefficients between first and third trimester for systolic and diastolic blood pressure and mean arterial pressure were 0.47, 0.46, and 0.49, respectively. The specific scatterplots are given in Supplementary material online, *Figures S1–S3*.

Table 3 shows that for systolic blood pressure, about 55% of the women, who started in the highest tertile in first trimester remained in the highest tertile in third trimester, while approximately 29% and 15% were in the middle and lowest tertiles, respectively. Similar patterns were observed for diastolic blood pressure and mean arterial pressure. The ORs for staying in the upper tertile from first to third trimester for systolic blood pressure and diastolic blood pressure were 3.09 (95% CI: 2.73, 3.50) and 3.28 (95% CI: 2.90, 3.69), respectively. A similar trend was observed for tertiles of mean arterial pressure. Blood pressure

Table 1 Subject characteristics by pregnancy health (n = 8236)[a]

	Non-hypertensive complicated pregnancy (n = 7762)	Pregnancy-induced hypertension (n = 306)	Preeclampsia (n = 168)	P-value[b]
Age (years)	29.7 (5.3)	30.0 (5.1)	28.8 (5.3)	0.086
Height (cm)	167.1 (7.4)	168.6 (7.2)	165.7 (7.3)	<0.001
Weight (kg)	65.5 (12.0)	74.9 (18.4)	68.5 (15.0)	<0.001
Pre-pregnancy body mass index (kg/m^2)	23.4 (4.1)	26.3 (6.2)	24.8 (5.3)	<0.001
Gestational weight gain (kg)	10.4 (5.0)	11.5 (6.9)	10.6 (6.5)	0.007
Parity (% nulliparous)	53.9	74.5	78.0	<0.001
Gestational age at intake (weeks)[c]	14.5 (10.4, 28.9)	13.7 (9.5, 24.0)	14.6 (10.3, 24.4)	0.011
Highest completed education (%)				
Primary school	10.6	7.8	12.5	0.016
Secondary school	41.7	48.4	49.4	
Higher education	38.7	39.2	28.0	
Missings	9.1	4.6	10.1	
Ethnicity (%)				
European	52.7	70.3	47.6	<0.001
Non-European	39.7	26.8	44.6	
Missings	7.6	2.9	7.7	
Alcohol consumption (%)				
No	42.5	40.5	47.6	0.241
Yes	43.4	48.7	41.1	
Missings	14.1	10.8	11.3	
Smoking habits (%)				
None	63.8	63.7	63.7	0.527
Yes	21.6	25.2	22.6	
Missings	14.5	11.1	13.7	
Caffeine intake (%)				
No	4.3	3.6	4.2	0.797
Yes	87.4	91.2	85.7	
Missings	8.3	5.2	10.1	

[a]Values are means (standard deviation) or percentages.
[b]Differences in subject characteristics between the groups were evaluated using one-way ANOVA tests for continuous variables and chi-square tests for proportions.
[c]Median (95% range).

tracking coefficients were lower in younger, shorter, and non-European women and in women with higher gestational weight gain (*Table 4*). Corresponding correlation coefficients are given in Supplementary material online, *Table S2*.

Table 5 shows that systolic and diastolic blood pressure change from first to second trimester was not associated with the risk of pregnancy-induced hypertension. Diastolic blood pressure change from first to second trimester was associated with the risk of pre-eclampsia [OR 1.20 (95% CI: 1.01, 1.44) per standard deviation of blood pressure change]. Second to third trimester changes in diastolic blood pressure and mean arterial pressure were associated with the risk of pregnancy-induced hypertension [OR 1.20 (95% CI: 1.06, 1.35) and OR 1.18 (95% CI: 1.04, 1.33) per standard deviation of blood pressure change, respectively]. Second to third trimester changes in systolic blood pressure, diastolic blood pressure, and mean arterial pressure were associated with the risk of preeclampsia [OR 1.22 (95% CI: 1.04, 1.43), OR 1.22 (95% CI: 1.03, 1.43), and OR 1.26 (95% CI: 1.07, 1.48) per standard deviation of blood pressure change, respectively].

Discussion

Results from this prospective cohort study showed that gestational blood pressure development is different from first trimester onwards between non-hypertensive pregnancies and pregnancies complicated by gestational hypertensive disorders. Systolic and diastolic blood pressure and mean arterial pressure track moderately during pregnancy. This tracking is influenced by maternal

Table 2 Blood pressure levels during pregnancy ($n = 8236$)[a]

Pregnancy period	Non-hypertensive complicated pregnancy ($n = 7762$)	Pregnancy-induced hypertension ($n = 306$)	Preeclampsia ($n = 168$)	*P*-value[b]
First trimester				
Systolic blood pressure	114.7 (11.8)	124.1 (12.3)	119.7 (12.4)	<0.001
Diastolic blood pressure	67.5 (9.0)	75.7 (10.1)	72.7 (10.2)	<0.001
Mean arterial pressure	83.2 (8.9)	91.8 (9.8)	88.3 (9.9)	<0.001
Second trimester				
Systolic blood pressure	115.8 (11.6)	126.2 (12.3)	120.9 (12.9)	<0.001
Diastolic blood pressure	66.4 (8.9)	75.9 (9.2)	73.4 (9.4)	<0.001
Mean arterial pressure	82.9 (8.8)	92.6 (9.1)	89.2 (9.5)	<0.001
Third trimester				
Systolic blood pressure	117.4 (11.6)	128.8 (12.9)	124.9 (13.1)	<0.001
Diastolic blood pressure	68.2 (8.8)	79.1 (9.7)	76.7 (9.4)	<0.001
Mean arterial pressure	84.6 (8.6)	95.7 (9.5)	92.8 (9.4)	<0.001

[a]Values are means (standard deviation).
[b]Differences in blood pressure levels between the groups were evaluated using one-way ANOVA tests.

characteristics. Systolic and diastolic blood pressure changes from second to third trimester are positively associated with the risk of gestational hypertensive disorders.

Methodological considerations

Some methodological issues need to be considered. One of the strengths of this study was the prospective data collection from early pregnancy onwards. We had a large sample size of 8482 participants with 22 287 blood pressure measurements. The response rate at baseline for participation in the study was 61%. The non-response would lead to biased effect estimates if the associations would be different between those included and not included in the analyses. However, this seems unlikely because biased estimates in large cohort studies mainly arise from loss to follow-up rather than from non-response at baseline.[15] Detailed information about a large number of potential confounding factors was available in this study. However, because of the observational design, residual confounding due to other socio-demographic and lifestyle related determinants might still be an issue. In addition, information on many covariates in this study was self-reported, which may have resulted in underreporting of certain adverse lifestyle-related determinants. Furthermore, blood pressure has a large within subject-variation and is also liable to measurement error. Measurement error might cause an underestimation of the true tracking correlation of blood pressure.[7] However, when tracking is used to examine the predictive value of early measurements to identify those at risk, measurement error will not bias the results, because measurement error also occurs in real clinical setting.[7] Finally, we had a relative small number of cases of pregnancy-induced hypertension and preeclampsia, which might indicate a selection towards a healthy, low-risk population. It might be of interest to perform a similar analysis in a high risk, hospital-based population.

Blood pressure development during pregnancy

Several studies have reported differences in blood pressure development between non-hypertensive-complicated pregnancies and pregnancies complicated by pregnancy-induced hypertension or preeclampsia.[5,6] A previous study among 202 primigravid women at high risk for gestational hypertensive disorders observed differences in the circadian variability of systolic and diastolic blood pressure between uncomplicated pregnancies and pregnancies complicated by gestational hypertensive disorders. Pregnancies leading to gestational hypertensive disorders had elevated blood pressure levels in first trimester.[6] In the same study, the known second trimester blood pressure dip was not present in complicated pregnancies, and blood pressure increased strongly in complicated pregnancies, particularly in those complicated by preeclampsia. We observed similar differences in the blood pressure patterns using office blood pressure measurements. Although we did not observe an absence of the mid-pregnancy dip in pregnancies complicated by gestational hypertensive disorders, we did observe that the mid-pregnancy dip was smaller and tended to occur earlier in pregnancy. We also observed a larger increase in blood pressure levels from second to third trimester in complicated pregnancies, particularly for pregnancies complicated by preeclampsia. Even though these observed differences in blood pressure development are highly statistically significant, it needs to be considered that both systolic blood pressure and diastolic blood pressure were within the physiological range of blood pressure variability. However, these differences might provide

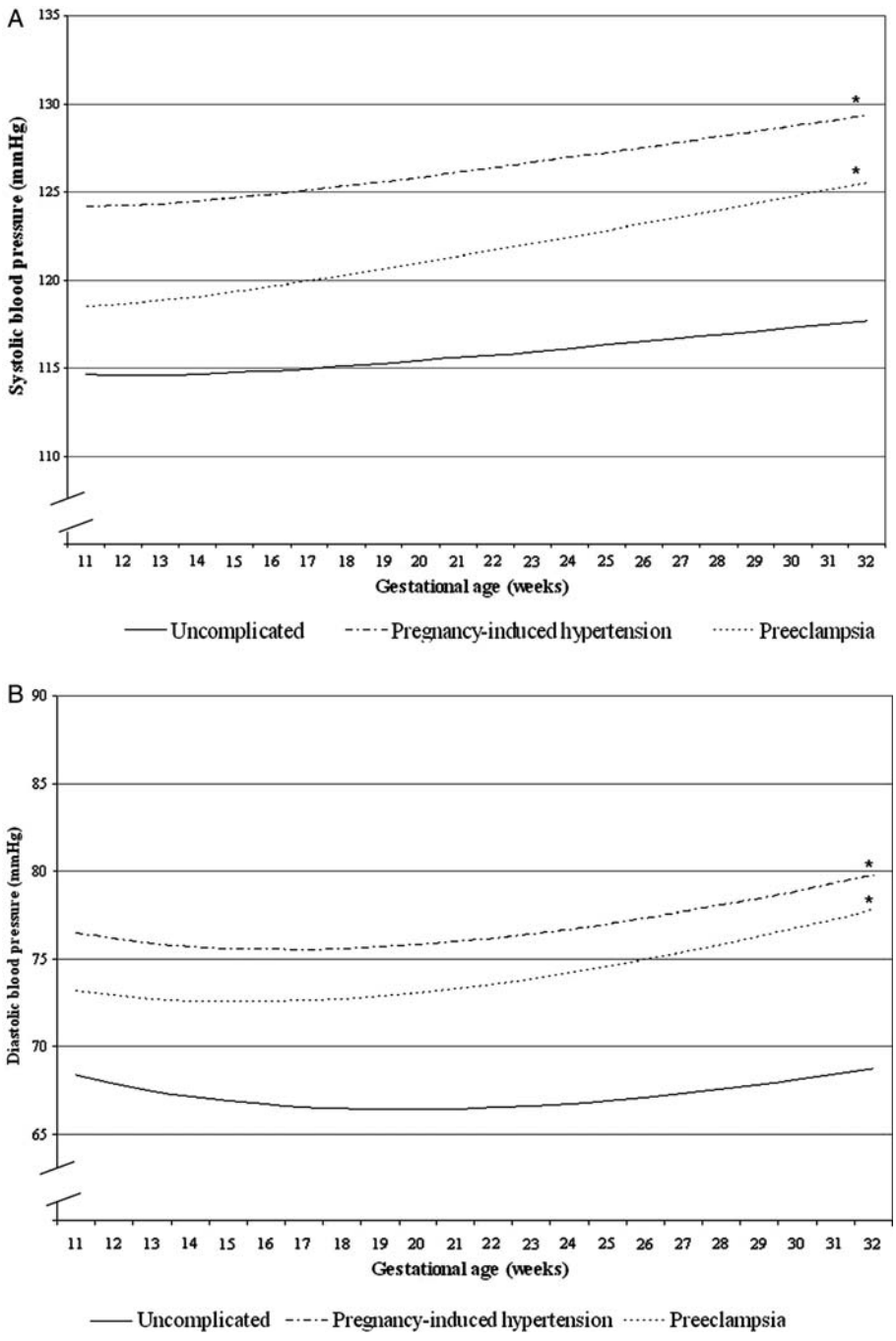

Figure 2 Blood pressure patterns in uncomplicated and complicated pregnancies. (*A*) Systolic blood pressure. Change in systolic blood pressure in mmHg for women with a pregnancy complicated by pregnancy-induced hypertension and women with a pregnancy complicated by preeclampsia compared with women with an uncomplicated pregnancy based on repeated measurement analysis (systolic blood pressure = $\beta_0 + \beta_1 *$ hypertensive complication $+ \beta_2 *$ gestational age $+ \beta_3 *$ gestational age$^{-2} + \beta_4 *$ hypertensive complication *gestational age). *P*-value reflects the significance level of β_4, which reflects the difference in change in blood pressure per week per pregnancy hypertensive complication, when compared with uncomplicated pregnancies. Estimates are given in Supplementary material online, *Table S1*. *$P < 0.05$. (*B*) Diastolic blood pressure. Change in diastolic blood pressure in mmHg for women with a pregnancy complicated by pregnancy-induced hypertension and women with a pregnancy complicated by preeclampsia compared with women with an uncomplicated pregnancy based on repeated measurement analysis (diastolic blood pressure = $\beta_0 + \beta_1 *$ hypertensive complication $+ \beta_2 *$ gestational age $+ \beta_3 *$ gestational age$^{0.5} + \beta_4 *$ hypertensive complication*gestational age). *P*-value reflects the significance level of β_4, which reflects the difference in change in blood pressure per week per pregnancy hypertensive complication, when compared with uncomplicated pregnancies. Estimates are given in Supplementary material online, *Table S1*. *$P < 0.05$.

Table 3 Blood pressure tracking from first to third trimester ($n = 6053$)[a,b]

Tertiles first trimester	Tertiles third trimester			*n*
	First	Second	Third	
Systolic blood pressure				
First	2.73 (2.43, 3.07)†	0.90 (0.80, 1.01)	0.33 (0.28, 0.37)†	2228
	n = 1202	*n* = 667	*n* = 359	
	53.9%	29.9%	16.1%	
Second	0.92 (0.81, 1.03)	1.19 (1.06, 1.34)†	0.94 (0.83, 1.05)	2028
	n = 701	*n* = 678	*n* = 649	
	34.6%	33.4%	32.0%	
Third	0.29 (0.25, 0.34)†	0.92 (0.81, 1.04)	3.09 (2.73, 3.50)†	1797
	n = 284	*n* = 524	*n* = 989	
	15.8%	29.2%	55.0%	
n	2187	1869	1997	6053
Diastolic blood pressure				
First	3.32 (2.95, 3.72)†	0.80 (0.71, 0.90)†	0.29 (0.25, 0.33)†	2209
	n = 1269	*n* = 609	*n* = 331	
	57.4%	27.6%	15.0%	
Second	0.76 (0.67, 0.85)†	1.42 (1.26, 1.60)†	0.95 (0.84, 1.07)	1865
	n = 626	*n* = 658	*n* = 581	
	33.6%	35.3%	31.2%	
Third	0.32 (0.29, 0.37)†	0.86 (0.76, 0.98)*	3.28 (2.90, 3.69)†	1979
	n = 371	*n* = 551	*n* = 1057	
	18.7%	27.8%	53.4%	
n	2266	1818	1969	6053
Mean arterial pressure				
First	3.44 (3.06, 3.87)†	0.73 (0.65, 0.81)†	0.27 (0.23, 0.31)†	2095
	n = 1146	*n* = 650	*n* = 299	
	54.7%	31.0%	14.3%	
Second	0.67 (0.60, 0.75)†	1.48 (1.33, 1.66)†	1.01 (0.89, 1.14)	1957
	n = 587	*n* = 775	*n* = 595	
	30.0%	39.6%	30.4%	
Third	0.29 (0.25, 0.34)†	0.89 (0.79, 1.01)	3.40 (2.69, 3.50)†	2001
	n = 302	*n* = 595	*n* = 1104	
	15.1%	29.7%	55.2%	
n	2035	2020	1998	6053

[a]Values are odds ratio (95% confidence interval) (number and percentage of women that remain in the same tertile) to remain in the same tertiles of systolic blood pressure, diastolic blood pressure, and mean arterial pressure. Estimates are from multiple imputed data.
[b]Model is adjusted for gestational age at intake, gestational age, maternal age, educational level, parity, ethnicity, pre-pregnancy body mass index, gestational weight gain, smoking habits, alcohol consumption, and caffeine intake.
*P-value < 0.05.
†P-value < 0.01.

clues on how to earlier identify those women at increased risk of gestational hypertensive disorders.

Blood pressure tracking

We have previously shown that obese and overweight women already had a higher blood pressure in first trimester, when compared with normal weight women. These differences remained stable throughout pregnancy.[16] Our current study shows that systolic blood pressure, diastolic blood pressure, and mean arterial pressure track moderately from first to third trimester. Blood pressure tracking in pregnancy might help to early identify those women that are at high risk to develop gestational hypertensive disorders. Several variables have been identified that might influence or predict tracking in studies among children and adults. It has been shown that length of follow-up is inversely associated with the tracking correlation.[17,18] We observed that the tracking correlation for systolic and diastolic blood pressure was stronger between first and second trimester and second and third trimester compared with the tracking correlation between first and third trimester. Also, some studies have suggested that blood pressure tracking is different in different ethnic populations.[17,19,20] Accordingly, we observed differences in tracking coefficients for diastolic blood pressure and mean arterial pressure in European women and non-European women. Furthermore, age, overweight, and weight change have been suggested to influence tracking.[17,20,21] A study among men and women showed the tracking correlation for

Table 4 Maternal characteristics and blood pressure tracking coefficients[a]

Maternal characteristics	Systolic blood pressure, regression coefficient (95% CI)	*P*-value	Diastolic blood pressure, regression coefficient (95% CI)	*P*-value	Mean arterial pressure, regression coefficient (95% CI)	*P*-value
Age (years)						
<25 years ($n = 1801$)	0.43 (0.38, 0.49)	<0.001	0.37 (0.31, 0.42)	<0.001	0.37 (0.31, 0.42)	<0.001
25–35 years ($n = 5432$)	0.48 (0.45, 0.50)	<0.001	0.47 (0.45, 0.50)	<0.001	0.47 (0.45, 0.50)	<0.001
>35 years ($n = 1249$)	0.41 (0.34, 0.47)	<0.001	0.47 (0.40, 0.53)	<0.001	0.47 (0.40, 0.53)	<0.001
	Interaction $P = 0.820$		Interaction $P < 0.001$		Interaction $P = 0.027$	
Height (cm)						
<165 cm ($n = 3677$)	0.42 (0.39, 0.46)	<0.001	0.42 (0.38, 0.45)	<0.001	0.44 (0.41, 0.48)	<0.001
165–175 cm ($n = 3626$)	0.46 (0.42, 0.49)	<0.001	0.47 (0.44, 0.51)	<0.001	0.50 (0.47, 0.53)	<0.001
>175 cm ($n = 1149$)	0.44 (0.39, 0.49)	<0.001	0.48 (0.43, 0.53)	<0.001	0.50 (0.45, 0.55)	<0.001
	Interaction $P = 0.166$		Interaction $P < 0.001$		Interaction $P = 0.001$	
Pre-pregnancy body mass index (kg/m^2)						
Normal ($n = 4968$)	0.44 (0.41, 0.46)	<0.001	0.43 (0.40, 0.46)	<0.001	0.46 (0.43, 0.49)	<0.001
Overweight ($n = 1298$)	0.45 (0.39, 0.51)	<0.001	0.39 (0.34, 0.45)	<0.001	0.42 (0.37, 0.48)	<0.001
Obesity ($n = 567$)	0.44 (0.35, 0.52)	<0.001	0.48 (0.39, 0.56)	<0.001	0.50 (0.42, 0.58)	<0.001
	Interaction $P = 0.590$		Interaction $P = 0.715$		Interaction $P = 0.592$	
Gestational weight gain (kg)						
<7 kg ($n = 1638$)	0.47 (0.42, 0.51)	<0.001	0.48 (0.44, 0.53)	<0.001	0.50 (0.46, 0.54)	<0.001
7–11.9 kg ($n = 2877$)	0.44 (0.41, 0.48)	<0.001	0.46 (0.42, 0.49)	<0.001	0.48 (0.44, 0.51)	<0.001
>12 kg ($n = 2010$)	0.45 (0.40, 0.49)	<0.001	0.43 (0.39, 0.48)	<0.001	0.47 (0.43, 0.51)	<0.001
	Interaction $P = 0.014$		Interaction $P < 0.001$		Interaction $P = 0.005$	
Parity						
Nulliparous ($n = 4666$)	0.45 (0.42, 0.48)	<0.001	0.43 (0.40, 0.46)	<0.001	0.46 (0.43, 0.49)	<0.001
Multiparous ($n = 3711$)	0.46 (0.43, 0.50)	<0.001	0.47 (0.43, 0.50)	<0.001	0.50 (0.46, 0.53)	<0.001
	Interaction $P = 0.574$		Interaction $P = 0.099$		Interaction $P = 0.115$	
Highest completed education						
Primary school ($n = 896$)	0.43 (0.35, 0.51)	<0.001	0.43 (0.35, 0.51)	<0.001	0.47 (0.40, 0.55)	<0.001
Secondary school ($n = 3572$)	0.48 (0.44, 0.51)	<0.001	0.46 (0.43, 0.50)	<0.001	0.50 (0.46, 0.53)	<0.001
Higher education ($n = 3244$)	0.45 (0.43, 0.48)	<0.001	0.45 (0.42, 0.49)	<0.001	0.48 (0.44, 0.51)	<0.001
	Interaction $P = 0.693$		Interaction $P = 0.968$		Interaction $P = 0.615$	
Ethnicity						
European ($n = 4508$)	0.45 (0.42, 0.48)	<0.001	0.49 (0.46, 0.52)	<0.001	0.51 (0.48, 0.54)	<0.001
Non-European ($n = 3335$)	0.43 (0.39, 0.47)	<0.001	0.39 (0.35, 0.43)	<0.001	0.43 (0.39, 0.47)	<0.001
	Interaction $P = 0.448$		Interaction $P < 0.001$		Interaction $P = 0.001$	
Alcohol consumption						
No ($n = 3620$)	0.46 (0.43, 0.50)	<0.001	0.46 (0.42, 0.49)	<0.001	0.49 (0.46, 0.52)	<0.001
Yes ($n = 3676$)	0.45 (0.42, 0.49)	<0.001	0.45 (0.42, 0.48)	<0.001	0.48 (0.45, 0.51)	<0.001
	Interaction $P = 0.433$		Interaction $P = 0.666$		Interaction $P = 0.553$	
Smoking habits						
None ($n = 5045$)	0.47 (0.44, 0.50)	<0.001	0.47 (0.44, 0.49)	<0.001	0.50 (0.47, 0.53)	<0.001
Yes ($n = 1847$)	0.42 (0.37, 0.47)	<0.001	0.42 (0.37, 0.47)	<0.001	0.45 (0.40, 0.49)	<0.001
	Interaction $P = 0.072$		Interaction $P = 0.079$		Interaction $P = 0.042$	
Caffeine intake						
No ($n = 359$)	0.49 (0.38, 0.60)	<0.001	0.54 (0.45, 0.64)	<0.001	0.55 (0.46, 0.65)	<0.001
Yes ($n = 7404$)	0.46 (0.43, 0.48)	<0.001	0.45 (0.43, 0.47)	<0.001	0.48 (0.46, 0.50)	<0.001
	Interaction $P = 0.672$		Interaction $P = 0.550$		Interaction $P = 0.504$	

[a]Values are regression coefficients (95% CI) from first to third trimester for systolic blood pressure, diastolic blood pressure, and mean arterial pressure.

Table 5 Blood pressure development and the risks of pregnancy-induced hypertension and preeclampsia (n = 8236)[a,b]

Pregnancy period	Pregnancy-induced hypertension[b]	Preeclampsia[b]
First to second trimester		
Systolic blood pressure	1.06 (0.93, 1.20)	1.00 (0.84, 1.20)
Diastolic blood pressure	1.05 (0.92, 1.20)	1.20 (1.01, 1.44)*
Mean arterial pressure	1.06 (0.93, 1.21)	1.14 (0.95, 1.37)
Second to third trimester		
Systolic blood pressure	1.09 (0.97, 1.23)	1.22 (1.04, 1.43)*
Diastolic blood pressure	1.20 (1.06, 1.35)†	1.22 (1.03, 1.43)*
Mean arterial pressure	1.18 (1.04, 1.33)†	1.26 (1.07, 1.48)†
First to third trimester		
Systolic blood pressure	1.15 (1.01, 1.31)*	1.23 (1.02, 1.47)*
Diastolic blood pressure	1.28 (1.12, 1.46)†	1.42 (1.18, 1.70)†
Mean arterial pressure	1.27 (1.11, 1.45)†	1.40 (1.16, 167)†

[a]Values are odds ratios (95% confidence interval) that reflect the difference in risks of pregnancy-induced hypertension and preeclampsia per standard deviation change in blood pressure level between trimesters. Estimates are from multiple imputed data.
[b]Model is adjusted for gestational age at intake, gestational age at each pregnancy period, educational level, maternal age, ethnicity, parity, pre-pregnancy body mass index, gestational weight gain, smoking habits, alcohol consumption, and caffeine intake.
*P-value < 0.05.
†P-value < 0.01.

different age categories; for women aged 20–24, the tracking correlation for systolic blood pressure was 0.43 and the tracking correlation for diastolic blood pressure was 0.59, while for women aged 35–39 the tracking correlation was 0.64 and 0.68, respectively.[20] A study among Australian children reported that tracking of blood pressure, especially systolic blood pressure, was influenced by body mass index and change in body mass index.[21] Those individuals in the highest quartile of body mass index and those individuals in the highest quartile of weight gain had higher risks of persistence of high blood pressure levels. Similarly, maternal age, pre-pregnancy body mass index, and gestational weight gain might influence tracking. We observed that especially tracking of diastolic blood pressure and mean arterial pressure were influenced by maternal characteristics such as in older age and lower gestational weight gain.

Finally, systolic blood pressure, diastolic blood pressure, and mean arterial pressure tracked equally. However, diastolic blood pressure and mean arterial pressure were more strongly associated with the risks of pregnancy-induced hypertension and preeclampsia when compared with systolic blood pressure. This might indicate that diastolic blood pressure and mean arterial pressure have a higher predictive accuracy for gestational hypertensive disorders than systolic blood pressure.

Conclusion

Blood pressure tracks moderately during pregnancy. Second to third trimester increases in systolic and diastolic blood pressure are associated with the risk of gestational hypertensive disorders. Blood pressure tracking is related to maternal characteristics. Further research is needed focused on factors influencing blood pressure tracking and their associations with gestational hypertensive disorders.

Supplemental material

Supplementary material is available at *European Heart Journal* online.

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