ARTICLE

Association of maternal home blood pressure trajectory during pregnancy with infant birth weight: the BOSHI study

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Abstract
This study investigated the association between maternal home blood pressure (HBP) trajectory during pregnancy and infant birth weight. A total of 755 pregnant women were included in this prospective cohort study. A group-based trajectory model identified six trajectory groups for home systolic blood pressure (SBP), diastolic BP (DBP), and mean arterial pressure (MAP). Next, the association of HBP trajectory groups with infant birth weight was evaluated using a general linear model considering potential confounding factors. For home SBP and MAP, the trajectory groups with a low-steep J-curve, moderate J-curve, little high J-curve, and high J-curve were significantly associated with lower infant birth weight than the low-J-curve group. Among the trajectory groups for home DBP, the moderate–steep J-curve, little high J-curve, and high J-curve were significantly associated with lower infant birth weight than the group with low-J-curve. The effect sizes of the trajectory groups varied in infant birth weight from -0.21 standard deviations (SDs) (95% confidence interval (CI): -0.42 to -0.01 SD) to -1.13 SD (95% CI: -1.54 to -0.72 SD). In the analyses of infant birth weight in grams, effect sizes that were significantly associated with infant birth weight varied from -84 g (95% CI: -167 to -1 g) to -567 g (95% CI: -732 to -402 g). Trajectory groups with a moderate–reverse J-curve for home SBP, DBP, and MAP were not significantly associated with infant birth weight. Maternal HBP trajectory during pregnancy was an indicator of infant birth weight. Further studies evaluating the associations between HBP during pregnancy and other perinatal outcomes are needed.

Introduction

Hypertensive disorders of pregnancy (HDP), a common perinatal complication, are a risk factor for adverse perinatal outcomes due to inadequate uteroplacental perfusion [1, 2]. In addition, HDP are also a risk factor for future maternal

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diseases, including cardiovascular disease, coronary heart disease, heart failure, and stroke [3]. Therefore, the evaluation of maternal blood pressure (BP) during pregnancy is essential in prenatal management. In principle, HDP are diagnosed based on clinic blood pressure (CBP) measurements assessed within the medical environment [4, 5]. Several studies have reported a J-curve change in CBP values during pregnancy [6, 7]. Furthermore, a change in CBP values during pregnancy is an indicator of perinatal outcomes, including infant birth weight and length of gestation [8–10].

For the general population, several guidelines recommend home blood pressure (HBP) measurements, as an out-of-office measurement approach, in addition to CBP measurements, to diagnose and classify hypertension as follows: hypertension, white-coat hypertension, and masked hypertension [5, 11]. Compared with CBP, HBP has shown strong predictive power for cardiovascular diseases and target organ damage [12].

In addition, several guidelines in the field of obstetrics suggest performing HBP measurements in addition to CBP measurements during pregnancy [4, 13–15]. However, investigations evaluating the association between maternal HBP values during pregnancy and perinatal outcomes are limited [16]. Infant birth weight, a perinatal outcome, is inversely associated with coronary heart disease, type 2 diabetes mellitus (DM), and end-stage renal diseases later in life [17–19]. Since infant birth weight has decreased and the frequency of low birth weight infants has grown in Japan since 1980, the potential for an increased incidence of DM and hypertension has been underlined [20, 21]. Although maternal HBP values change during pregnancy similarly to the J-curve change in CBP values, the association of HBP trajectories with infant birth weight is unknown [22, 23]. Therefore, this study was conducted to investigate the association between maternal HBP trajectories during pregnancy and infant birth weight.

Methods

Study design and participants

This study was part of the Babies and their parents' longitudinal Observation in Suzuki memorial Hospital on Intrauterine period (BOSHI) study, a prospective cohort study. The BOSHI study was conducted at the Suzuki Memorial Hospital, an obstetrical and gynecological hospital in the Sendai City area, Miyagi prefecture, Japan [24–28]. The Institutional Review Board of the Tohoku University School of Medicine and the Hospital Review Board of Suzuki Memorial Hospital approved the study protocol. Details of the BOSHI study have been described previously [24, 26].

A total of 4278 women were diagnosed with an intrauterine pregnancy between October 16, 2006 and July 31, 2010 at the Suzuki Memorial Hospital. Of 1611 women who were informed of the BOSHI study, 1066 women consented to participate. Women who consented after delivery ($n = 178$) or those who experienced twin pregnancies ($n = 8$) were excluded, and the remaining 880 women were included in this study.

Home blood pressure measurement during pregnancy

Physicians, midwives, or pharmacists instructed subjects on how to measure HBP after enrollment. HBP was measured according to the Japanese Society of Hypertension guidelines for self-monitoring of BP at home [29]. Subjects were asked to measure their HBP on their upper arm every morning, within 1 h of waking, after micturition, before breakfast, while seated, and after resting for at least 1 min [24, 26].

HBP was measured using an HEM-747IC or HEM-7080IC (Omron Health care, Kyoto, Japan), a semiautomatic device based on the cuff-oscillometric method and equipped with a digital display system [24, 26]. These devices used cuffs, and the algorithms were equivalent to the Omron T9P, which has been validated in pregnant women [30]. After the HBP values were entered on the survey forms, the values were entered into the database. The mean arterial pressure (MAP) was calculated based on the following formula: $(SBP − DBP)/3 + DBP$. The number of HBP measurements achieved at <10 weeks of gestation or at ≥41 weeks of gestation was too small to be analyzed in this study. Therefore, we used the average home SBP, DBP, and MAP values for each 1-week interval measured between the period of 10 weeks 0 days and 40 weeks 6 days.

Infant birth weight

Infant birth weight in grams was collected from the medical records. Information on the delivery week, parity, and infant sex was also collected from medical records to calculate the standard deviation (SD) value for infant birth weight because the reference values for Japanese infant birth weights are based on delivery week, parity, infant sex, and birth weight [31].

Other variables used in this study

Maternal age at the time of consent to research participation, body weight at the last prenatal checkup before delivery, information about assisted reproductive technology (ART), history of HDP, and the expected date of confinement

(EDC) were collected from medical records. The EDC was confirmed by fetal crown-rump length as measured by ultrasonography at <12 weeks of gestation. The season of the EDC was defined as follows: spring (March, April, and May), summer (June, July, and August), autumn (September, October, and November), and winter (December, January, and February). Maternal height, prepregnancy body weight, family history of hypertension, smoking status, and alcohol consumption data were also collected with questionnaires and surveys by midwives. Smoking status was classified as follows: no smoking before conception, smoking until conception was recognized, and smoking during pregnancy. Alcohol consumption was classified as follows: no alcohol intake before conception, alcohol intake until conception was recognized, and alcohol intake during pregnancy. The prepregnancy body mass index (BMI) was calculated as follows: prepregnancy body weight in kilograms/(height in meters) [2]. Gestational weight gain was calculated as follows: body weight at the last prenatal checkup before delivery − prepregnancy body weight. Maternal diseases, including chronic hypertension, hyperthyroidism, hypothyroidism, antiphospholipid syndrome, and immunoglobulin A nephropathy, and obstetric complications, including HDP, placental abruption, and gestational DM (GDM), were also obtained from medical records.

In principle, HDP were diagnosed based on the CBP value [32]. In Japan, CBP is measured at prenatal checkups, which are conducted every 4 weeks at <23 weeks of gestation, once every 2 weeks at 23–35 weeks of gestation, and once per week at ≥36 weeks of gestation [24]. The method of measuring CBP in this study has been described previously [26].

Statistical analyses

First, we applied a group-based trajectory model (GBTM) to explore maternal HBP trajectory groups during pregnancy [33]. The quadratic order of the polynomial functions of the gestational week in each HBP trajectory group used was based on that from previous studies [22, 24, 34]. Next, we determined the number of HBP trajectory groups with each HBP trajectory function expressed using both a point estimate and 95% confidence interval. Details of the analysis using a GBTM are described in Supplementary Information.

We then explored maternal factors related to the HBP trajectory group assignment using a multinomial logistic regression model. Finally, we investigated the association between HBP trajectory groups and infant birth weight using a general linear model. HBP trajectory groups, as the exposures, and infant birth weight in SD value or in grams, as the outcome, were included in the model. Model 1 was a

crude analysis. In model 2, infant birth weight in grams was regressed on the trajectory groups and potential confounding factors, including maternal age at the time of consent to research participation, height, prepregnancy BMI, parity, gestational weight gain, ART, family history of hypertension, smoking status, alcohol consumption, history of HDP, hyperthyroidism, hypothyroidism, season of expected date confinement, and infant sex. In model 2 for infant birth weight as an SD score, parity, delivery week, and infant sex were not included because the SD value of infant birth weight was calculated based on parity, delivery week, and infant sex in Japan [31]. Maternal age, height, prepregnancy BMI, and gestational weight gain were included as continuous variables in the model. HDP was not included in the model as an independent variable because it would become an intermediate variable. As an additional analysis, model 3 included average home SBP, DBP, or MAP at 10–15 weeks of gestation as the baseline HBP, in addition to the variables in model 2. Because the average home SBP, DBP, or MAP at 10–15 weeks of gestation had missing data, we applied multiple imputation. As the missing pattern was monotone, we used a regression imputation method. We constructed an imputation model using both independent variables and dependent variables in model 2 and HDP as a potential auxiliary variable. After 30 data sets were created, the same analysis was conducted for each data set. Next, the results of each analysis were combined using Rubin's rule [35].
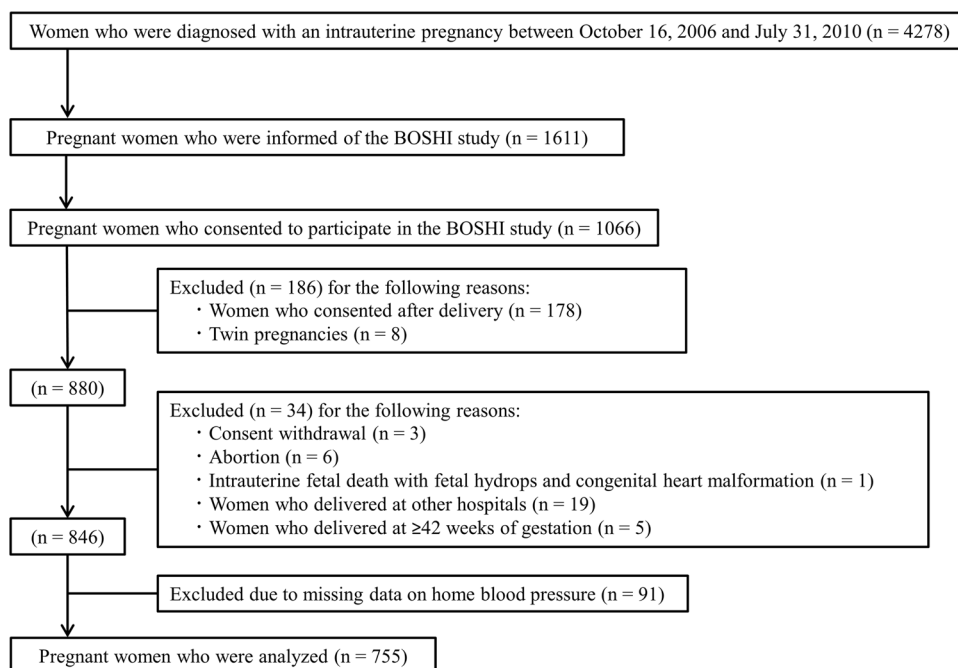
A two-sided p value < 0.05 was considered statistically significant. We used SAS software, version 9.4 (SAS Institute Inc., Cary, North Carolina, USA) to perform all statistical analyses.

Results

Maternal characteristics of the study participants

Figure 1 shows the flow chart of this study. Among the 880 women enrolled, women who withdrew consent ($n = 3$), underwent an abortion ($n = 6$), experienced intrauterine fetal death with fetal hydrops and congenital heart malformation ($n = 1$), delivered at other hospitals ($n = 19$), delivered at ≥42 weeks of gestation ($n = 5$) (due to lack of reference of Japanese infant birth weight at ≥42 weeks of gestation), and had missing HBP data during pregnancy ($n = 91$) were excluded from the study. Finally, 755 pregnant women were analyzed in this study.

Table 1 shows the maternal and neonatal characteristics of the analyzed subjects. The number and percentage of subjects who had HDP were 91% and 12.1%, respectively. The mean (SD) of infant birth weight in grams and those in SD values were 3062 (403) g and 0.1 (1.0), respectively.

Fig. 1 Flow chart of participants in this study


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Women who were diagnosed with an intrauterine pregnancy between October 16, 2006 and July 31, 2010 (n = 4278)

Pregnant women who were informed of the BOSHI study (n = 1611)

Pregnant women who consented to participate in the BOSHI study (n = 1066)

Excluded (n = 186) for the following reasons:
 · Women who consented after delivery (n = 178)
 · Twin pregnancies (n = 8)

(n = 880)

Excluded (n = 34) for the following reasons:
 · Consent withdrawal (n = 3)
 · Abortion (n = 6)
 · Intrauterine fetal death with fetal hydrops and congenital heart malformation (n = 1)
 · Women who delivered at other hospitals (n = 19)
 · Women who delivered at ≥42 weeks of gestation (n = 5)

(n = 846)

Excluded due to missing data on home blood pressure (n = 91)

Pregnant women who were analyzed (n = 755)
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Trajectory groups for HBP during pregnancy

Six trajectory groups each for home SBP, DBP, and MAP measurements during pregnancy were identified independently using a GBTM (Fig. 2). As shown in Supplementary Table 1, all models satisfied the diagnostic criteria of model accuracy described in the statistical analysis section in Supplementary Information [33].

Figure 2 shows the estimated functions of the home SBP, DBP, and MAP trajectory groups during pregnancy. Trajectory groups included group 1 (low-J-curve), group 2 (low-steep J-curve), group 4 (moderate–reverse J-curve), group 5 (little high J-curve), and group 6 (high J-curve) for all the home SBP, DBP, and MAP measurements. Home SBP and MAP trajectory group 3 and home DBP trajectory group 3 were called moderate J-curve and moderate–steep J-curve, respectively. Almost all home SBP and DBP trajectory groups were <135/85 mmHg except for group 6 for home DBP.

Among the home SBP trajectory groups, group 2 (low-steep J-curve) had the greatest increase in SBP at ≥20 weeks of gestation. In contrast, the SBP in group 4 (moderate–reverse J-curve) decreased from 10 to 30 weeks of gestation and then slightly increased. Other trajectory groups showed similar shapes to each other, although the SBP values at 10 weeks of gestation differed. For the home DBP trajectory groups, group 3 (moderate–steep J-curve) showed the greatest increase in DBP at ≥20 weeks of gestation. Group 4 (moderate–reverse J-curve) showed a decrease in DBP from 10 to ~30 weeks of gestation and then DBP increased slightly. Group 6 (high J-curve) had the greatest decrease in DBP from 10 to ~25 weeks of gestation, with a rise in DBP towards 40 weeks of gestation. The six home MAP trajectory groups had shapes similar to those of the home SBP trajectory groups.

Association between maternal characteristics and HBP trajectory group assignment during pregnancy

Supplementary Tables 2–4 (supplementary information) show the differences in maternal and neonatal characteristics according to the home SBP, DBP, and MAP trajectory groups, respectively. Supplementary Tables 5–7 show the adjusted odds ratios of maternal factors for the home SBP, DBP, and MAP trajectory groups, respectively. Pre-pregnancy BMI, gestational weight gain, family history of hypertension, and season of EDC were significantly related to the home SBP, DBP, and MAP trajectory group assignments. Maternal height and smoking during pregnancy were associated with the home SBP trajectory group assignment. Associations between parity and home SBP, DBP, and MAP trajectory groups were not statistically significant.

Association between HBP trajectory groups during pregnancy and infant birth weight

Tables 2 and 3 show the results of the association between HBP trajectory groups and infant birth weight as SD values and grams, respectively.

In model 2, relative to home SBP, women who belonged to groups 2 (low-steep J-curve), 3 (moderate J-curve), 5 (little high J-curve), and 6 (high J-curve) delivered

Table 1 Maternal and neonatal characteristics of the study participants

Characteristics	Study participants
Number of subjects	755
Maternal characteristics	
Age at the time of consent, years	31.9 (4.8)
<25 years, n (%)	61 (8.1)
25–29.9 years, n (%)	204 (27.0)
30–34.9 years, n (%)	278 (36.8)
≥35 years, n (%)	212 (28.1)
Height, cm	158.4 (5.3)
Prepregnancy body weight, kg	54.8 (9.5)
Prepregnancy BMI, kg/m²	21.8 (3.6)
Gestational weight gain, kg	10.1 (4.0)
Primipara, n (%)	437 (57.9)
Pregnancy established by ART, n (%)	15 (2.0)
Family history of hypertension, n (%)	283 (37.5)
Smoking, n (%)	
No smoking before conception	636 (84.2)
Until conception was recognized	89 (11.8)
Smoking during pregnancy	30 (4.0)
Alcohol intake, n (%)	
No alcohol intake before conception	414 (54.8)
Until conception was recognized	329 (43.6)
Alcohol intake during pregnancy	12 (1.6)
Season of expected date of confinement, n (%)	
Spring	152 (20.1)
Summer	198 (26.2)
Fall	209 (27.7)
Winter	196 (26.0)
Medical history, n (%)	
HDP in prior pregnancy	31 (4.1)
Hyperthyroidism	4 (0.5)
Hypothyroidism	2 (0.3)
Antiphospholipid syndrome	0 (0.0)
Immunoglobulin A nephropathy	0 (0.0)
Average home blood pressure value at 10–15 weeks of gestation (mmHg)[a]	
Home SBP	107 (14)
Home DBP	64 (10)
Home MAP	79 (11)
Obstetric complications, n (%)	
HDP	91 (12.1)
Placental abruption	3 (0.4)
GDM	9 (1.2)
Preterm delivery (Delivery at <37 weeks of gestation)	20 (2.7)
Delivery week, weeks	39.7 (1.2)
Neonatal characteristics	
Sex (male/female), n (%)	390 (51.7)/365 (48.3)
Birth weight, g	3064 (394)
Birth weight, SD value	0.1 (1.0)
Low birth weight (<2500 g), n (%)	54 (7.2)

Data are described as the mean (standard deviation) or numbers (percentages)

ART assisted reproductive technology, *BMI* body mass index, *DBP* diastolic blood pressure, *GDM* gestational diabetes mellitus, *HDP* hypertensive disorders of pregnancy, *SBP* systolic blood pressure

[a]The number and percentage of missing data were 138 and 18.3%

significantly lower infant birth weight infants compared with those who belonged to group 1 (low-J-curve). In model 2, relative to home DBP, women who belonged to groups 3 (moderate–steep J-curve), 5 (little high J-curve), and 6 (high J-curve) delivered significantly lower infant birth weight infants compared with those who belonged to group 1 (low-J-curve). In model 2, relative to home MAP, women who belonged to groups 2 (low-steep J-curve), 3 (moderate J-curve), 5 (little high J-curve), and 6 (high J-curve) delivered significantly lower infant birth weight infants compared with those who belonged to group 1 (low-J-curve), with the exception of the association between group 2 (low-steep J-curve) and infant birth weight measured as an SD value. For home SBP, DBP, and MAP, group 4 (moderate–reverse J-curve) was not significantly associated with infant birth weight.

In model 3, almost all associations between HBP trajectory groups and infant birth weight were similar, although the effect sizes were slightly weakened compared with those of model 2.

Discussion

To the best of our knowledge, this study showed for the first time that maternal HBP trajectory during pregnancy was an indicator of infant birth weight. HBP trajectory during pregnancy may provide health care providers information that reflects perinatal outcome. Previous studies have reported an inverse linear association between infant birth weight and adult hypertension and adult-onset DM in Japan [36–38]. Katanoda et al. reported that a 100 g increase in birth weight had significantly lower odds of adult-onset DM in Japan. Conversely, a 100 g decrease in birth weight had higher odds of adult-onset DM [38]. Almost all effect sizes derived from the HBP trajectory groups which were statistically significantly associated with lower infant birth weight, were decreases of 100 g or more. Therefore, the impact of maternal HBP trajectory to effect sizes in infant birth weight in this study would be clinically meaningful in Japan. Even after adjustment for HBP at 10–15 weeks of gestation, HBP trajectory was an indicator of infant birth weight. The higher number of BP measurements used for the trajectory model, compared with the number of BP measurements in early pregnancy, might have contributed to the stronger association; additional studies might be necessary to validate this comparison.

In this study, subjects who had a family history of hypertension or those whose season of EDC was spring or winter had significantly higher odds of belonging to the HBP trajectory groups that were significantly associated with lower infant birth weight. Smoking during pregnancy also had significantly higher odds of assignment to a home
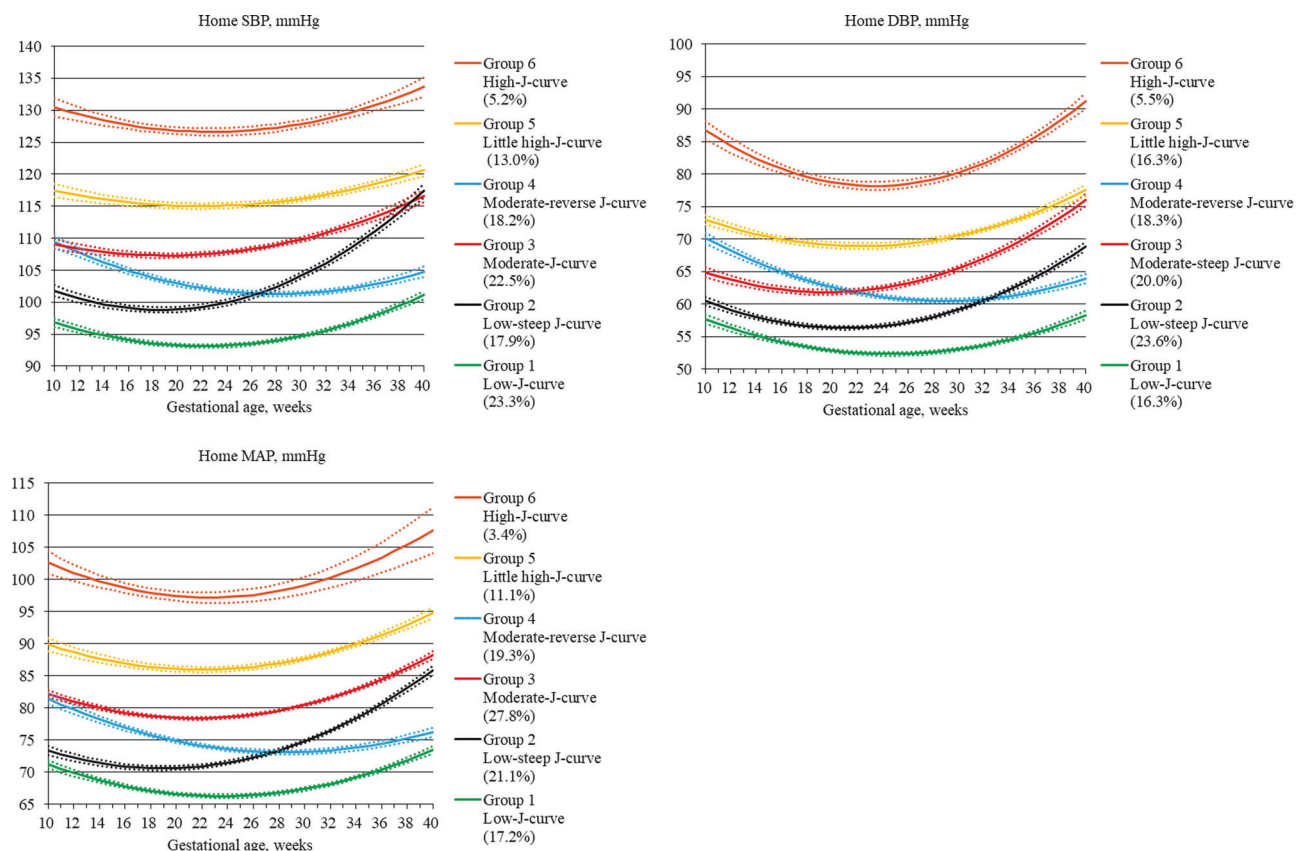
Fig. 2 Home blood pressure trajectory groups during pregnancy. Solid and dotted lines show a point estimate and 95% confidence interval, respectively, for each home blood pressure trajectory function. BP blood pressure, DBP diastolic blood pressure, MAP mean arterial pressure, SBP systolic blood pressure

SBP trajectory group that was significantly associated with lower infant birth weight. Therefore, family history of hypertension, season of EDC, and smoking status during pregnancy may represent important indicators of HBP trajectory during pregnancy.

The findings of this study were consistent with those of a previous study indicating that HBP during pregnancy was associated with perinatal outcome. Inoue et al. reported that a high HBP value at <20 weeks of gestation was a risk factor for HDP, diagnosed based on CBP values at ≥20 weeks of gestation [39].

The percentage of HDP in HBP trajectory groups with significantly lower infant birth weight infants was higher than that in the groups that were not statistically associated with infant birth weight in this study. Therefore, the HBP trajectory might reflect inadequate uteroplacental perfusion due to HDP.

Although studies supporting recommendations for the measurement of HBP in addition to CBP during pregnancy are limited, several guidelines have proposed a classification for HDP based on both CBP and HBP [4, 14]. In 2018, the International Society for the Study of Hypertension in Pregnancy suggested a classification for HDP using both

CBP and HBP values [4]. At <20 weeks of gestation, chronic hypertension is diagnosed if CBP is ≥140/90 mmHg and HBP is ≥135/85 mmHg. White-coat hypertension is diagnosed with CBP ≥ 140/90 mmHg and HBP < 135/85 mmHg. Masked hypertension is also diagnosed if CBP is <140/90 mmHg and HBP is ≥135/85 mmHg [4]. The French Society of Hypertension also indicated that HBP ≥ 135/85 mmHg during pregnancy is considered pathological [40]. These diagnostic criteria are derived from thresholds used in the general population [5]. However, HBP ≥ 135/85 mmHg as a threshold for diagnosis of HDP regardless of gestational age may not be appropriate as HBP changes during pregnancy. Mikami et al. proposed provisional criteria for diagnosis of HDP according to gestational age using HBP [23]. In their study, HBP values equal to CBP 140/90 mmHg were 120.8/83.5 mmHg, 126.0/85.2 mmHg, and 136.3/89.3 mmHg in the first, second, and third trimesters, respectively [23]. In this study, several maternal HBP trajectory groups were significantly associated with lower infant birth weight even when home SBP and home DBP values throughout pregnancy were <135 mmHg and <85 mmHg, respectively. Further accumulation of evidence regarding the association between HBP during pregnancy

Table 2 Association between home blood pressure trajectory groups during pregnancy and infant birth weight in SD values

Trajectory groups	Difference in infant birth weight, SD values					
	Model 1[a]		Model 2[b]		Model 3[c]	
	Estimate (95% CI)	P value	Estimate (95% CI)	P value	Estimate (95% CI)	P value
Home SBP						
Group 1: Low-J-curve	Reference	–	Reference	–	Reference	–
Group 2: Low-steep J-curve	−0.13 (−0.35 to 0.09)	0.3	−0.21 (−0.42 to −0.01)	0.04	−0.19 (−0.40 to 0.02)	0.07
Group 3: Moderate J-curve	−0.11 (−0.32 to 0.10)	0.3	−0.34 (−0.55 to −0.14)	0.001	−0.29 (−0.52 to −0.07)	0.01
Group 4: Moderate–reverse J-curve	−0.07 (−0.29 to 0.15)	0.5	−0.16 (−0.37 to 0.05)	0.1	−0.13 (−0.35 to 0.10)	0.3
Group 5: Little high J-curve	−0.02 (−0.25 to 0.25)	1.0	−0.38 (−0.62 to −0.13)	0.003	−0.29 (−0.59 to 0.01)	0.06
Group 6: High J-curve	−0.16 (−0.50 to 0.18)	0.4	−0.69 (−1.05 to −0.34)	0.0001	−0.56 (−1.01 to −0.12)	0.01
Average home SBP at 10–15 weeks of gestation, per 1 mmHg increase	–	–	–	–	0.00 (−0.01 to 0.00)	0.3
Home DBP						
Group 1: Low-J-curve	Reference	–	Reference	–	Reference	–
Group 2: Low-steep J-curve	−0.07 (−0.29 to 0.16)	0.6	−0.12 (−0.33 to 0.09)	0.3	−0.10 (−0.31 to 0.11)	0.4
Group 3: Moderate–steep J-curve	−0.24 (−0.47 to −0.01)	0.04	−0.34 (−0.57 to −0.12)	0.003	−0.30 (−0.54 to −0.06)	0.02
Group 4: Moderate–reverse J-curve	0.13 (−0.12 to 0.36)	0.3	0.00 (−0.23 to 0.23)	1.0	0.05 (−0.20 to 0.30)	0.7
Group 5: Little high J-curve	−0.15 (−0.40 to 0.10)	0.2	−0.40 (−0.64 to −0.16)	0.001	−0.31 (−0.6 to −0.02)	0.04
Group 6: High J-curve	−0.14 (−0.49 to 0.20)	0.4	−0.57 (−0.92 to −0.22)	0.001	−0.45 (−0.88 to −0.01)	0.04
Average home DBP at 10–15 weeks of gestation, per 1 mmHg increase	–	–	–	–	−0.01 (−0.02 to 0.01)	0.3
Home MAP						
Group 1: Low-J-curve	Reference	–	Reference	–	Reference	–
Group 2: Low-steep J-curve	−0.07 (−0.30 to 0.15)	0.5	−0.18 (−0.40 to 0.03)	0.09	−0.18 (−0.39 to 0.03)	0.1
Group 3: Moderate J-curve	−0.16 (−0.37 to 0.06)	0.1	−0.42 (−0.63 to −0.22)	<0.0001	−0.40 (−0.63 to −0.17)	0.001
Group 4: Moderate–reverse J-curve	0.03 (−0.20 to 0.27)	0.8	−0.11 (−0.33 to 0.11)	0.3	−0.09 (−0.32 to 0.14)	0.4
Group 5: Little high J-curve	0.03 (−0.24 to 0.30)	0.8	−0.37 (−0.64 to −0.10)	0.008	−0.33 (−0.65 to −0.001)	0.04
Group 6: High J-curve	−0.55 (−0.96 to −0.14)	0.009	−1.13 (−1.54 to −0.72)	<0.0001	−1.07 (−1.55 to −0.58)	<0.0001
Average home MAP at 10–15 weeks of gestation, per 1 mmHg increase	–	–	–	–	0.00 (−0.01 to 0.01)	0.6

ART assisted reproductive technology, *BMI* body mass index, *CI* confidence interval, *DBP* diastolic blood pressure, *GDM* gestational diabetes mellitus, *HDP* hypertensive disorders of pregnancy, *MAP* mean arterial pressure, *SBP* systolic blood pressure

[a]Crude values

[†]Adjusted for maternal age, height, prepregnancy BMI, gestational weight gain, ART, family history of hypertension, smoking status, alcohol drinking, gestational diabetes mellitus, HDP in prior pregnancy, hyperthyroidism, hypothyroidism, and season of expected date confinement

[c]Adjusted for average home SBP, DBP, or MAP at 10–15 weeks of gestation in addition to Model 2, respectively

Table 3 Association between home blood pressure trajectory groups during pregnancy and infant birth weight in grams

Trajectory groups	Differences in infant birth weight, grams					
	Model 1[a]		Model 2[b]		Model 3[c]	
	Estimate (95% CI)	*P* value	Estimate (95% CI)	*P* value	Estimate (95% CI)	*P* value
Home SBP						
Group 1: Low-J-curve	Reference	–	Reference	–	Reference	–
Group 2: Low-steep J-curve	−47 (−40 to 135)	0.3	−84 (−167 to −1)	0.04	−82 (−166 to 2)	0.06
Group 3: Moderate J-curve	−8 (−81 to 96)	0.9	−141 (−223 to −59)	0.001	−134 (−226 to −42)	0.005
Group 4: Moderate–reverse J-curve	−13 (−81 to 107)	0.8	−75 (−160 to 10)	0.08	−70 (−160 to 21)	0.1
Group 5: Little high J-curve	62 (−41 to 165)	0.2	−138 (−239 to −38)	0.007	−126 (−245 to −4)	0.04
Group 6: High J-curve	−90 (−231 to 50)	0.2	−360 (−504 to −216)	<0.0001	−341 (−520 to −161)	0.0002
Average home SBP at 10–15 weeks of gestation, per 1 mmHg increase	–	–	–	–	−1 (−4 to 2)	0.7
Home DBP						
Group 1: Low-J-curve	Reference	–	Reference	–	Reference	–
Group 2: Low-steep J-curve	−46 (−136 to 45)	0.3	−68 (−153 to 17)	0.1	−66 (−151 to 20)	0.1
Group 3: Moderate–steep J-curve	−76 (−169 to 18)	0.1	−116 (−207 to −25)	0.01	−108 (−206 to −10)	0.03
Group 4: Moderate–reverse J-curve	49 (−48 to 145)	0.3	−6 (−99 to 86)	0.9	3 (−99 to 106)	1.0
Group 5: Little high J-curve	−74 (−172 to 25)	0.1	−173 (−271 to −75)	0.001	−158 (−280 to −36)	0.01
Group 6: High J-curve	−109 (−247 to 29)	0.1	−290 (−431 to −149)	<0.0001	−268 (−446 to −90)	0.003
Average home DBP at 10–15 weeks of gestation, per 1 mmHg increase	–	–	–	–	−1 (−5 to 3)	0.7
Home MAP						
Group 1: Low-J-curve	Reference	–	Reference	–	Reference	–
Group 2: Low-steep J-curve	−52 (−143 to 38)	0.3	−105 (−190 to −20)	0.02	−105 (−190 to −19)	0.02
Group 3: Moderate J-curve	−57 (−142 to 29)	0.2	−170 (−253 to −86)	<0.0001	−170 (−264 to −77)	0.0004
Group 4: Moderate–reverse J-curve	22 (−70 to 115)	0.6	−50 (−137 to 38)	0.3	−49 (−142 to 43)	0.3
Group 5: Little high J-curve	7 (−101 to 114)	0.9	−159 (−269 to −49)	0.005	−160 (−291 to −29)	0.02
Group 6: High J-curve	−320 (−485 to −156)	0.0001	−567 (−732 to −402)	<0.0001	−568 (−763 to −372)	<0.0001
Average home MAP at 10–15 weeks of gestation, per 1 mmHg increase	–	–	–	–	0 (−4 to 4)	1.0

ART assisted reproductive technology, *BMI* body mass index, *CI* confidence interval, *DBP* diastolic blood pressure, *GDM* gestational diabetes mellitus, *HDP* hypertensive disorders of pregnancy, *MAP* mean arterial pressure, *SBP* systolic blood pressure

[a]Crude values

[b]Adjusted for maternal age, height, prepregnancy BMI, gestational weight gain, ART, family history of hypertension, smoking status, alcohol drinking, GDM, HDP in prior pregnancy, hyperthyroidism, hypothyroidism, season of expected date confinement, parity (primipara or not), and infant sex

[c]Adjusted for average home SBP, DBP, or MAP at 10–15 weeks of gestation in addition to Model 2, respectively

and other perinatal outcomes, including placental abruption, fetal growth restriction, and fetal distress, is needed to determine the threshold of HBP for diagnosing HDP.

It should be noted that this study does not overlook the importance of CBP measurements, as findings relative to the association of CBP during pregnancy with perinatal outcomes have accumulated in previous studies [9, 10, 41–43]. Although several studies have reported that the number of prenatal visits was reduced by HBP measurements during pregnancy, no previous studies have clarified whether HBP measurements, in addition to CBP measurements, improve perinatal outcomes [44, 45]. Therefore, further studies will need to examine whether HBP measurements in combination with CBP measurements during pregnancy would improve perinatal outcomes. In addition, pregnant women must buy devices for self-monitoring of HBP, except those who participate in clinical studies, if a health care provider

in Japan recommends that a pregnant woman monitor HBP. Therefore, the costs and benefits of measuring HBP during pregnancy should be examined.

This study has several limitations. First, this study was conducted at a single hospital. Although external validity will likely support our results, as in our previous studies, the findings in this study need to be reproduced in other populations [26, 28]. Second, the association of the HBP trajectory group with other perinatal outcomes, including placental abruption and preterm delivery, could not be evaluated because the sample size was too small to be analyzed. Therefore, studies with a larger sample size will be needed. Third, differences in angiogenic imbalances among HBP trajectory groups could not be examined because neither soluble fms-like tyrosine kinase 1 nor placental growth factor levels were measured in this study. Furthermore, we could not assess whether subjects

adequately measured BP at home, although physicians, midwives, or pharmacists individually instructed the subjects on how to measure HBP after enrollment.

In conclusion, maternal HBP trajectory during pregnancy was an indicator of infant birth weight. Thus, health care providers may consider HBP meaningful clinical information for pregnant women who monitor HBP values during pregnancy.

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Compliance with ethical standards

Conflict of interest TO, YI, TO, and HM concurrently hold the directorship at the Tohoku Institute for Management of Blood Pressure, which is supported by Omron Health care Co. Ltd. HM is also currently involved in collaborative research with Omron Health care in another study. Omron Health care Co. Ltd. was not involved in the study design, paper methodology, writing, or drafting of the paper or its conclusions.

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