

ORIGINAL ARTICLE

# Maternal clinic and home blood pressure measurements during pregnancy and infant birth weight: the BOSHI study

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This prospective cohort study compared measurements of maternal home blood pressure (HBP) with clinic blood pressure (CBP) before 20 weeks' gestation to determine associations with the risk of delivering a lower birth weight infant. A total of 605 Japanese women were included. Exposures were initial CBP, made between 10 weeks 0 days and 19 weeks 0 days, and HBP for comparison made within 1 week of CBP. Outcome was infant's birth weight, categorized and ranked as follows:  $\geq 3500$  g, 3000–3499 g, 2500–2999 g and  $< 2500$  g. The proportional odds model with possible confounding factors was applied to compare the associations between CBP and HBP on infant birth weight. When both CBP and HBP were included simultaneously, the adjusted odds ratios (ORs) per 1 standard deviation (1s.d.) increase in clinic and home diastolic BP (DBP) were 1.06 (95% confidence interval (CI): 0.87–1.30) and 1.28 (95% CI: 1.04–1.58), respectively. The adjusted ORs per 1s.d. increase in clinic and home mean arterial pressure (MAP) were 1.02 (95% CI: 0.83–1.24) and 1.29 (95% CI: 1.04–1.59), respectively. Systolic BP measurement was not associated with infant birth weight. In conclusion, high maternal home DBP and MAP before 20 weeks' gestation was associated with a higher risk of lower infant birth weight than clinic DBP and MAP. Therefore, in addition to CBP, it may be worth having pregnant women measure HBP to determine the risk of lower infant birth weight. *Hypertension Research* (2016) 39, 151–157; doi:10.1038/hr.2015.108; published online 29 October 2015

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## INTRODUCTION

Birth weight reflects the quality of the intrauterine environment.<sup>1</sup> There are continuous inverse relationships between an infant's birth weight and future diseases such as hypertension, coronary artery disease, diabetes mellitus and stroke.<sup>2</sup> An infant's birth weight is affected by several factors during pregnancy including maternal physique, gestational weight gain, smoking status, complications and seasonality.<sup>3–7</sup> One common maternal complication that affects birth weight is hypertensive disorder in pregnancy, including chronic hypertension and pregnancy-induced hypertension (PIH), which is defined as hypertension that occurs after 20 weeks' gestation.<sup>8,9</sup> The prevalence of hypertensive disorder in pregnancy is about 5–10%, and the perinatal prognosis is poor owing to premature delivery, stillbirth or maternal death in addition to impaired fetal growth.<sup>8,10,11</sup> Furthermore, women with pre-eclampsia have sustained high blood pressure (BP) after delivery.<sup>12</sup> Therefore, BP monitoring throughout pregnancy is an essential part of perinatal care.

Conventionally, maternal BP measurements to diagnose hypertensive disorder in pregnancy have been made based on clinic BP (CBP) levels.<sup>9,13</sup> High maternal CBP and abnormal uterine artery doppler findings were related to abnormal level of soluble fms-like tyrosine kinase 1, soluble endoglin and placental growth factor.<sup>14</sup> An inverse association between high maternal CBP levels during pregnancy and perinatal prognosis, in particular infant's birth weight, has been reported.<sup>6</sup>

Several studies have also reported on the use of home BP (HBP) measurements.<sup>15–19</sup> Results in both a general population and in patients with hypertension indicated that HBP was a better predictor of cardiovascular events than CBP.<sup>15–19</sup> Although HBP during pregnancy was examined in previous studies,<sup>20–23</sup> no study has compared HBP with CBP during pregnancy to determine if these measurements are inversely related to infant birth weight. Because previous studies have shown that high CBP even before the clinical onset of PIH was related to PIH and small-for-gestational age (SGA)

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**Table 1** Baseline characteristics of study participants

Characteristic	Values
Number of subjects	605
<i>Maternal characteristics</i>	
Age (years)	31.7 (4.7)
<20 years (%)	0.8
20–34.9 years (%)	72.7
≥35 years (%)	26.5
Height (cm)	158.3 (5.2)
Pre-pregnancy weight (kg)	54.4 (9.1)
Pre-pregnancy BMI (kg m <sup>-2</sup> )	21.7 (3.5)
Gestational weight gain (kg)	10.2 (3.9)
Primipara (%)	59.0
History of PIH (%)	4.0
Smoking (%)	
No smoking before conception	84.3
Until conception was recognized	11.7
Smoking during pregnancy	4.0
Alcohol intake (%)	
No alcohol intake before conception	53.5
Until conception was recognized	44.8
Alcohol intake during pregnancy	1.7
Season of conception (%)	
Spring	22.5
Summer	19.8
Autumn	28.3
Winter	29.4
Family history of hypertension (%)	37.0
Hypertensive disorders in pregnancy (%)	8.9
Chronic hypertension <sup>a</sup> (%)	1.7
PIH (%)	7.4
Gestational hypertension	5.8
Pre-eclampsia	1.7
Superimposed pre-eclampsia	0.5
Placental abruption (%)	0.5
GDM (%)	0.7
SLE (%)	0.002
<i>Number of BP measurements (median, 25–75%, range)</i>	
Clinic BP	2, 2–2, 1–2
Home BP	4, 2–6, 1–7
<i>Gestational week at BP measurement</i>	
Clinic BP	14.0 (1.8)
Home BP	14.4 (1.8)
<i>BP values (mm Hg)</i>	
Clinic SBP	109 (12)
Clinic DBP	67 (9)
Clinic MAP	81 (9)
Home SBP	105 (9)
Home DBP	63 (7)
Home MAP	77 (8)
<i>Neonatal characteristics</i>	
Sex (male/female; %)	51.4/48.6
Gestational age at delivery, week	39.7 (1.3)
Preterm delivery (%)	2.6
SGA (%) <sup>b</sup>	6.5
Birth weight (g)	3057 (391)
<2500 (%)	7.4

**Table 1 (Continued)**

Characteristic	Values
2500–2999 (%)	35.9
3000–3499 (%)	44.3
≥3500 (%)	12.4

Abbreviations: BP, blood pressure; BMI, body-mass index; DBP, diastolic BP; GDM, gestational diabetes mellitus; MAP, mean arterial pressure; PIH, pregnancy-induced hypertension; SBP, systolic BP; SGA, small-for-gestational age; SLE, systemic lupus erythematosus. Data are expressed as mean (s.d.) or percentages unless otherwise stated.  
<sup>a</sup>Chronic hypertension without antihypertensive drugs before 20 weeks' gestation.  
<sup>b</sup>SGA was defined as a birth weight below the 10th percentile of Japanese infants.

infants,<sup>13,24</sup> we focused on maternal BP before 20 weeks' gestation in this study.

The aim of this study was to compare the association of HBP vs. CBP measurements before 20 weeks' gestation on the risk of delivering infants with a lower birth weight.

## METHODS

### Study design and participants

This study was a part of the Babies and their parents' longitudinal Observation in Suzuki Memorial Hospital on Intrauterine period (BOSHI) study—a prospective cohort study.<sup>23,25,26</sup> The BOSHI study was conducted in Suzuki Memorial Hospital, an obstetrical and gynecological hospital in the Sendai city area, Miyagi prefecture in Japan. Details of the study are described elsewhere.<sup>23,25,26</sup> Study protocols were approved by the institutional review board of Tohoku University School of Medicine and by the review board of Suzuki Memorial Hospital. All participants gave informed consent.

In the BOSHI study, 4069 women had a confirmed intrauterine pregnancy and booked delivery in this hospital between 16 October 2006, and 31 May 2010. Among them, 1473 women had the BOSHI study explained to them during this period, and 765 women consented to participate in this study before 20 weeks' gestation. We excluded women treated with antihypertensive medication before 20 weeks' gestation owing to chronic hypertension (6 women) and twin pregnancies (7 women). Fifteen women with chronic hypertension who did not use antihypertensive drugs before 20 weeks' gestation were included in this study. Therefore, the remaining 752 women were included in this study.

### HBP and CBP measurements

The methods for HBP<sup>23,25,26</sup> and CBP<sup>26</sup> measurement are described elsewhere.<sup>23,25,26</sup> BP was measured using a semi-automatic device (HEM-7471C or HEM-70801C for HBP and HEM7051T for CBP, respectively; Omron Healthcare, Kyoto, Japan) which is based on the cuff-oscillometric method and has a digital display system. These devices used cuffs and algorithms that were validated in pregnant women.<sup>27</sup> The initial CBP was made between 10 weeks 0 days and 19 weeks 0 days, and the HBP measurement for comparison was made within 1 week of the CBP measurement. Therefore, the gestational age at HBP measurement ranged from 10 weeks 0 days to 19 weeks 6 days. CBP and HBP, which were each measured at least once, were evaluated. The mean of CBP values was used if more than 1 measurement was made. For HBP data, the mean of the first record on each day, which was made within 1 week of the CBP measurement, was used if more than one CBP measurement was used. Mean arterial pressure (MAP) of CBP and HBP was calculated as diastolic BP (DBP)+(systolic BP (SBP) – DBP)/3 in CBP and HBP, respectively.

### Data collection and statistical analysis

Medical information about participants was collected from medical records, by questionnaires, and via surveys by midwives. The associations of maternal CBP and HBP with infant birth weight were examined using the proportional odds model with possible confounding factors, rather than multivariate linear regression model.<sup>28</sup> Details of data collection and statistical analysis are described in the Supplementary Information.

## RESULTS

### Maternal and neonatal characteristics of study participants

After 752 women were enrolled, 147 women were excluded. Reasons for exclusion from analysis and differences in maternal and neonatal characteristics between study participants and excluded women are described in the Supplementary Information. The remaining 605 women were analyzed. Table 1 shows baseline characteristics of participants who were analyzed. There were no women with a history of chronic kidney disease or women diagnosed with antiphospholipid syndrome before pregnancy. There was only one woman with systemic lupus erythematosus. Among study subjects, 73 women (12.1%) had only one CBP measurement. In addition, not all subjects measured HBP every day. The numbers of HBP measurements during a week were once (11.1%), twice (14.9%), 3 times (18.2%), 4 times (11.6%), 5 times (14.1%), 6 times (20.8%) and 7 times (9.4%).

### Association between maternal CBP and infant birth weight

Table 2 shows results of the association between CBP and infant birth weight. In all analyses, the proportional odds assumption was not rejected statistically. No strong multicollinearity among explanatory variables was confirmed. Although the second quartile of clinic SBP was associated with lower categories of infant's birth weight, no significant linear association between clinic SBP and infant birth weight existed ( $P$  for trend was 0.75). In contrast, higher clinic DBP was associated with lower infant's birth weight ( $P$  for trend was 0.007).

**Table 2 Association between CBP before 20 weeks' gestation and infant birth weight<sup>a</sup>**

BP value (mm Hg)	n	Adjusted OR (95% CI)	P-value of the score test <sup>b</sup>
<i>Clinic SBP</i>			
Quartile 1 (78.5–100.5)	154	1.00	0.28
Quartile 2 (101.0–107.0)	152	1.58 (1.01–2.48)	
Quartile 3 (107.5–114.5)	144	1.11 (0.70–1.76)	
Quartile 4 (115.0–172.0)	155	1.22 (0.76–1.95)	
$P$ for trend		0.75	0.23
Continuous variable (per 1s.d.) <sup>c</sup>		1.05 (0.89–1.24)	0.19
<i>Clinic DBP</i>			
Quartile 1 (42.0–59.5)	148	1.00	0.30
Quartile 2 (60.0–65.0)	154	1.48 (0.94–2.33)	
Quartile 3 (65.5–72.0)	152	1.35 (0.85–2.13)	
Quartile 4 (72.5–100.5)	151	2.08 (1.29–3.35)	
$P$ for trend		0.007	0.24
Continuous variable (per 1s.d.) <sup>c</sup>		1.21 (1.03–1.44)	0.22
<i>Clinic MAP</i>			
Quartile 1 (59.5–73.5)	151	1.00	0.17
Quartile 2 (73.7–79.5)	153	1.43 (0.91–2.24)	
Quartile 3 (79.7–86.0)	152	1.28 (0.81–2.02)	
Quartile 4 (86.2–115.3)	149	1.59 (0.99–2.57)	
$P$ for trend		0.10	0.19
Continuous variable (per 1s.d.) <sup>c</sup>		1.16 (0.98–1.37)	0.20

Abbreviations: 1s.d., 1 standard deviation; CI, confidence interval; CBP, clinic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; OR, odds ratio; SBP, systolic blood pressure.

<sup>a</sup>All models were adjusted by maternal age, pre-pregnancy BMI, GWG, parity, history of PIH, family history of hypertension, smoking status, alcohol intake, GDM, delivery week, infant's sex, season of conception and gestational week at BP measurement.

<sup>b</sup>The score test for the proportional odds assumption.  $P \geq 0.05$  indicates that the proportional odds assumption is not rejected statistically.

<sup>c</sup>1s.d. = 12 mm Hg for clinic SBP, 9 mm Hg for clinic DBP and 9 mm Hg for clinic MAP.

The adjusted odds ratio was 1.21 (95% confidence interval: 1.03–1.44) for each 1s.d. elevation of clinic DBP. Clinic MAP was not significantly associated with infant's birth weight.

### Association between maternal HBP and infant birth weight

The association between maternal HBP and infant birth weight is shown in Table 3. As with CBP, the proportional odds assumption was not rejected by the score test. There was no strong multicollinearity among explanatory variables.

In terms of home SBP, although the second quartile of home SBP was associated with lower categories of infant's birth weight, no significant linear association existed ( $P$  for trend was 0.25). On the other hand, both home DBP and home MAP were at risk for delivering lower categories of infant's birth weight ( $P$  for trend were 0.002 and 0.007, respectively). The adjusted odds ratios of home DBP and home MAP with each 1s.d. of increased BP were 1.33 (95% confidence interval, 1.11–1.58) and 1.30 (95% confidence interval, 1.09–1.55), respectively.

### Comparison of CBP and HBP in terms of infant birth weight

CBP and HBP were included into the model as continuous variables simultaneously per 1s.d. change in the variables (Tables 4 and 5). In this analysis, the gestational week at CBP but not HBP measurement was included as an explanatory variable because gestational week at BP measurement had strong multicollinearity among CBP and HBP (that is, the results of analyses that included gestational week at HBP measurement, but not CBP, were comparable).

In terms of SBP, neither clinic SBP nor home SBP was significantly associated with infant birth weight (Table 4). Furthermore, the goodness-of-fit did not improve when clinic SBP and home SBP were included simultaneously compared with when each BP was included separately based on the likelihood ratio test (Tables 5,  $P=0.08$  and 0.53, respectively). On the other hand, the statistical significance of home DBP remained, whereas that of clinic DBP diminished when clinic DBP and home DBP were included simultaneously (Table 4). The likelihood ratio test showed a significant improvement when home DBP was included in the analysis in addition to clinic DBP, whereas the inverse was not true (Tables 5,  $P=0.02$  and 0.45, respectively). In addition, the statistical significance of home MAP also remained even after clinic MAP was included simultaneously (Table 4). As with DBP, the goodness-of-fit improved when home MAP was included in addition to clinic MAP, although the inverse was not true (Tables 5,  $P=0.02$  and 0.60, respectively).

## DISCUSSION

These results indicate that maternal HBP before 20 weeks' gestation was strongly related to the risk of delivering a lower birth weight infant compared with CBP. To the best of our knowledge, this is the first report that compared CBP and HBP measurements with the association with lower infant birth weight during pregnancy. Furthermore, this was also the first study that showed the association between high HBP during pregnancy and lower infant birth weight. Our results are similar to studies conducted in a general population or hypertensive subjects in whom HBP was a better predictor for prognosis than CBP, although the final outcomes examined in our study and these other studies differed.<sup>15–19</sup> Several reasons for differences between CBP and HBP on lower birth weight should be considered. First, the white coat effect that occurs when CBP is measured might overestimate maternal hemodynamics. Second, the number and time of measurements among CBP and HBP were different. These discrepancies between CBP and HBP might have contributed to our findings.

Furthermore, we performed additional analyses to determine whether SBP or DBP was more strongly associated with lower infant birth weight (results are described in Supplementary Tables 2 and 3). As a result, both clinic and home DBP measurements were associated with a risk of lower birth weight infants, whereas SBP measurements were not. This finding is comparable with previous studies that were conducted in a general population and pregnant women. In a general population, the Framingham Heart Study showed that the impact of DBP on coronary heart disease was stronger than that of SBP in patients younger than 50 years.<sup>29</sup> A recent study also showed that among subjects younger than 50 years, high DBP levels, as measured

by 24-h ambulatory BP monitoring, were the predominant risk factor for coronary complications, whereas SBP levels were not.<sup>30</sup> In the generation R study, increments in DBP during pregnancy were inversely associated with infant's birth weight and SGA, whereas increments in SBP were not.<sup>6</sup> In regard to the risk of low birth weight, the point estimate of the adjusted odds ratio of clinic DBP was higher than that of clinic SBP, although direct comparisons were not made.<sup>6</sup> Furthermore, DBP at the first trimester was negatively associated with fetal crown to rump length, which was related to low birth weight and SGA; SBP was not significantly associated with these variables.<sup>31</sup> One possible reason for this finding might be owing to the different mechanisms of BP increase between SBP and DBP. McEniery *et al.*<sup>32</sup> reported that isolated systolic hypertension resulted from the increase in stroke volume and/or aortic stiffness in young people but not from the increase in peripheral vascular resistance. In contrast, DBP increases occur when peripheral vascular resistance increases.<sup>32</sup> On the basis of different mechanisms of BP increase, Poon *et al.*<sup>13</sup> also stated the importance of DBP during pregnancy. After conception, maternal vascular resistance decreases by trophoblast invasion and by remodeling of uterine spiral artery.<sup>33</sup> This change is thought to be important to supply sufficient uteroplacental blood flow for ideal fetal

**Table 3 Association between HBP before 20 weeks' gestation and infant birth weight<sup>a</sup>**

BP value (mm Hg)	n	Adjusted OR (95% CI)	P-value of the score test <sup>b</sup>
<b>Home SBP</b>			
Quartile 1 (85.0–98.3)	150	1.00	0.31
Quartile 2 (98.5–103.8)	154	1.82 (1.14–2.90)	
Quartile 3 (104.0–110.3)	149	1.37 (0.86–2.19)	
Quartile 4 (110.4–136.0)	152	1.53 (0.92–2.54)	
P for trend		0.25	0.28
Continuous variable (per 1 s.d.) <sup>c</sup>		1.19 (0.99–1.42)	0.25
<b>Home DBP</b>			
Quartile 1 (43.0–57.6)	150	1.00	0.31
Quartile 2 (57.8–62.5)	154	1.85 (1.17–2.93)	
Quartile 3 (62.6–67.3)	150	2.57 (1.60–4.12)	
Quartile 4 (67.4–94.3)	151	2.01 (1.23–3.29)	
P for trend		0.002	0.24
Continuous variable (per 1 s.d.) <sup>c</sup>		1.33 (1.11–1.58)	0.21
<b>Home MAP</b>			
Quartile 1 (57.3–71.6)	154	1.00	0.22
Quartile 2 (71.7–76.2)	151	1.56 (0.98–2.47)	
Quartile 3 (76.3–81.8)	150	1.96 (1.23–3.13)	
Quartile 4 (82.0–107.7)	150	1.90 (1.15–3.14)	
P for trend		0.007	0.28
Continuous variable (per 1 s.d.) <sup>c</sup>		1.30 (1.09–1.55)	0.22

Abbreviations: 1 s.d., 1 standard deviation; CI, confidence interval; DBP, diastolic blood pressure; HBP, home blood pressure; MAP, mean arterial pressure; OR, odds ratio; SBP, systolic blood pressure.

<sup>a</sup>All models were adjusted by maternal age, pre-pregnancy BMI, GWG, parity, history of PIH, family history of hypertension, smoking status, alcohol intake, GDM, deliver week, infant's sex, season of conception and gestational week at BP measurement.

<sup>b</sup>The score test for the proportional odds assumption.  $P \geq 0.05$  indicates that the proportional odds assumption is not rejected statistically.

<sup>c</sup>1 s.d. = 9 mm Hg for home SBP, 7 mm Hg for home DBP and 8 mm Hg for home MAP.

**Table 5 Comparison of effects between CBP and HBP on infant birth weight (the Likelihood ratio tests)<sup>a</sup>**

Model	-2 log likelihood	Likelihood ratio <sup>b</sup>	P-value
<b>SBP</b>			
Model 1 (only CBP, per 1 s.d.) <sup>c</sup>	1157.38	3.11	0.08
Model 2 (only HBP, per 1 s.d.) <sup>c</sup>	1154.67	0.40	0.53
Model 3 (CBP and HBP, per 1 s.d.) <sup>c</sup>	1154.27	—	—
<b>DBP</b>			
Model 1 (only CBP, per 1 s.d.) <sup>c</sup>	1152.68	5.39	0.02
Model 2 (only HBP, per 1 s.d.) <sup>c</sup>	1147.85	0.56	0.45
Model 3 (CBP and HBP, per 1 s.d.) <sup>c</sup>	1147.29	—	—
<b>MAP</b>			
Model 1 (only CBP, per 1 s.d.) <sup>c</sup>	1154.78	5.33	0.02
Model 2 (only HBP, per 1 s.d.) <sup>c</sup>	1149.73	0.28	0.60
Model 3 (CBP and HBP, per 1 s.d.) <sup>c</sup>	1149.45	—	—

Abbreviations: 1 s.d., 1 standard deviation; CBP, clinic blood pressure; DBP, diastolic blood pressure; HBP, home blood pressure; MAP, mean arterial pressure; SBP, systolic blood pressure.

<sup>a</sup>Please refer adjustments in Table 2.

<sup>b</sup>The difference in -2 log likelihood between model 3 and either model 1 or model 2 that of each model, respectively.

<sup>c</sup>1 s.d. = 12 mm Hg for clinic SBP, 9 mm Hg for clinic DBP, 9 mm Hg for clinic MAP, 9 mm Hg for home SBP, 7 mm Hg for home DBP and 8 mm Hg for home MAP.

**Table 4 Comparison of effects between CBP and HBP on infant birth weight<sup>a</sup>**

Model	CBP	HBP	P-value of the score test <sup>b</sup>
	Adjusted OR (95% CI)	Adjusted OR (95% CI)	
SBP (per 1 s.d.) <sup>c</sup>	0.97 (0.80–1.17)	1.21 (0.98–1.49)	0.23
DBP (per 1 s.d.) <sup>c</sup>	1.06 (0.87–1.30)	1.28 (1.04–1.58)	0.24
MAP (per 1 s.d.) <sup>c</sup>	1.02 (0.83–1.24)	1.29 (1.04–1.59)	0.23

Abbreviations: 1 s.d., 1 standard deviation; CI, confidence interval; CBP, clinic blood pressure; DBP, diastolic blood pressure; HBP, home blood pressure; MAP, mean arterial pressure; OR, odds ratio; SBP, systolic blood pressure.

<sup>a</sup>Please refer adjustments in Table 2.

<sup>b</sup>The score test for the proportional odds assumption.  $P \geq 0.05$  indicates that the proportional odds assumption is not rejected statistically.

<sup>c</sup>1 s.d. = 12 mm Hg for clinic SBP, 9 mm Hg for clinic DBP, 9 mm Hg for clinic MAP, 9 mm Hg for home SBP, 7 mm Hg for home DBP and 8 mm Hg for home MAP.

growth.<sup>33</sup> Thus high maternal vascular resistance may have a worse effect on fetal growth. Previous studies reported that high resistance of the uterine artery, measured at the first trimester using ultrasonography, was predictive of intrauterine growth restriction and SGA.<sup>34,35</sup> Maternal total vascular resistance (TVR) includes and correlates with uteroplacental resistance.<sup>36</sup> Vasapollo *et al.* showed that maternal TVR at 20 to 22 weeks' gestation was predictive of adverse outcomes including fetal growth restriction and PIH.<sup>37</sup> Therefore, high maternal DBP may reflect high maternal TVR, in particular uteroplacental resistance, and subsequent fetal growth restriction and lower infant birth weight. MAP also reflects TVR.<sup>38</sup> From our results, we estimate that, compared with CBP, home DBP and MAP may more strongly reflect TVR during pregnancy.

Furthermore, the same analyses were performed after 6 subjects who delivered infants with macrosomia (that is, birth weight  $\geq 4000$  g) were excluded because several studies showed that macrosomia was a risk for type 2 diabetes and newborn complications.<sup>39,40</sup> After that, results were comparable (data not shown).

In this study, 73 women (12.1%) had one CBP measurement and 532 women (87.9%) had two CBP measurements. To examine the effect of difference in numbers of CBP measurements among study subjects, we reanalyzed the association between CBP and infant birth weight including numbers of CBP measurements as an explanatory variable in the proportional odds model. In this analysis, results were comparable (data not shown). Therefore, differences in numbers of CBP measurements among study subjects are unlikely to have had a strong effect on study findings.

There are several limitations to this study. First, this study was conducted in a single hospital and the rate of agreement to participate in this study was low (51.9%). Therefore, selection bias cannot be ruled out. However, the external validity of this study may be acceptable because the maternal characteristics of our study participants were similar to those in other studies conducted in other areas in Japan.<sup>41,42</sup> Second, although BP changes during pregnancy,<sup>43</sup> the influence of longitudinal changes in BP on infant birth weight was not considered. A decrease in maternal BP from early- to mid-gestation is referred to as the 'mid-pregnancy fall'.<sup>44</sup> This phenomenon is thought to arise from the decrease of peripheral vascular resistance<sup>45</sup> and tends to be associated with the clinical onset of pre-eclampsia.<sup>44</sup> Thus, this phenomenon may affect fetal growth and infant's birth weight. Further research about the association between mid-pregnancy fall and infant birth weight is needed. In addition, it was difficult to obtain comparisons of CBP and HBP in each trimester of pregnancy because only 193 women measured CBP and HBP during the first trimester. A larger sample size is needed to address this issue. Third, a comparison of the effect CBP *vs.* HBP on infant birth weight after 20 weeks' gestation was not determined. BP evaluation after 20 weeks' gestation is also important because PIH can develop in this period. Macdonald-Wallis *et al.*<sup>46</sup> reported a negative association between the increase in maternal BP after 18 weeks' gestation and infant birth weight in the Avon Longitudinal Study of Parents and Children (ALSPAC). We will examine this issue in the future. Fourth, other perinatal outcomes such as placental abruption, premature deliver and SGA infants could not be evaluated because the number of these events was too small. To clarify the impact of these outcomes, a larger sample size is needed. Fifth, diurnal variation of BP, which can be detected using 24-h ambulatory BP, was not assessed.<sup>47</sup> The reason that we evaluated HBP but not ambulatory BP as an alternative to CBP in our study was described previously.<sup>26</sup> Although health-care providers seem to prefer to use HBP over ambulatory BP in the field,<sup>48,49</sup> comparison of effects between ambulatory BP and other BP

measurements on perinatal outcome may be needed. Sixth, in general, maternal BP changes from preconception to early pregnancy.<sup>50</sup> Although it is important to evaluate the effects between HBP and CBP measured before conception on infant's birth weight and Mahendru *et al.*<sup>51</sup> recently reported that it was feasible to recruit women before conception, we were not able to collect the data before conception including BP because almost all women were recruited after diagnosis of intrauterine pregnancy. A prospective cohort study that recruits women before conception is needed to evaluate this issue. Seventh, we could not evaluate the effect of variability in HBP on infant birth weight because the numbers of HBP measurements were restricted to compare HBP and CBP in this study. Previous study reported variability in HBP was predictive of cardiovascular events in general population.<sup>52</sup> Therefore, variability in HBP during pregnancy may also be associated with perinatal outcomes. The other approach is needed to examine the association between variability in HBP and perinatal outcomes.

In conclusion, high maternal home DBP and MAP before 20 weeks' gestation was associated with a higher risk of lower infant birth weight than clinic DBP and MAP. HBP may be better than CBP to reflect increases in maternal peripheral vascular resistance. Therefore, in addition to CBP, it may be worth having pregnant women measure HBP to determine the risk of lower infant birth weight.

#### CONFLICT OF INTEREST

HM and YI have taken part in, and are currently involved with, collaborative research with Omron Healthcare.

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Supplementary Information accompanies the paper on Hypertension Research website (<http://www.nature.com/hr>)