Effect of change in posture on maternal functional hemodynamics at 35-37 weeks' gestation

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Maternal functional hemodynamics and change in posture

Key words: Third-trimester screening, Maternal cardiovascular function, Cardiac output, Total peripheral resistance, Posture, Preeclampsia

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ABSTRACT

Objective: To evaluate the effect of posture change from the supine to sitting position and before and after passive leg raising on maternal functional hemodynamics in pregnant women at 35-37 weeks' gestation and to compare the changes in pregnancies that subsequently developed preeclampsia (PE) and gestational hypertension (GH) to those who remained normotensive.

Methods: In 3,013 singleton pregnancies at 35-37 weeks' gestation maternal cardiovascular parameters were measured using an automated non-invasive cardiac monitor. The hemodynamic response to a change from the supine to the sitting position and before and after passive leg raising in the left lateral position was examined and compared between women who subsequently developed PE or GH and those who remained normotensive.

Results: In normotensive singleton pregnancies at 35-37 weeks' gestation, both change from the supine to the sitting position and passive leg raising were associated with increase in cardiac index and stroke volume index and decrease in total peripheral resistance index; there was no significant change in heart rate and a small increase in mean arterial pressure. In pregnancies that subsequently developed PE or GH, compared to normotensive pregnancies, cardiac index and stroke volume index were lower and total peripheral resistance index was higher. In general, change from the supine to the sitting position and passive leg raising were associated with similar but less marked changes in cardiovascular parameters as in normotensive pregnancies.

Conclusions: Paradoxically, in late third trimester normal pregnancies both change from the supine to the sitting position and passive leg raising may result in increase in preload with consequent increase in cardiac index and stroke volume index and decrease in total peripheral resistance index. In pregnancies that develop PE or GH the effects of postural change on cardiovascular parameters are similar but less marked than in normotensive pregnancies.

Introduction

Normal pregnancy is associated with a major increase in plasma volume, decrease in peripheral resistance and increase in cardiac output.[1] In contrast, preeclampsia (PE) is associated with plasma volume depletion, increase in peripheral resistance and decrease in cardiac output.[2,3] These cardiovascular alterations precede the clinical onset of the disease; a screening study in 3,013 singleton pregnancies at 35-37 weeks' gestation assessed maternal cardiovascular function using a non-invasive, bioreactance method and reported that in pregnancies that subsequently developed PE or gestational hypertension (GH) total peripheral resistance was increased and maternal cardiac output was reduced.[4,5]

Postural change from the supine to the sitting position would reduce venous return to the heart and therefore preload and in healthy non-pregnant individuals such change in posture is associated with decrease in cardiac output and increase in peripheral resistance; these changes are also observed in early pregnancy but the response is muted in late pregnancy because venous return is maintained due to the expanded plasma volume.[6] Passive leg raising increases preload and in healthy individuals such increase in preload is associated with increase in stroke volume because the normal heart operates in the ascending part of the Frank-Starling curve.[7]

The objective of this study in singleton pregnancies at 35-37 weeks' gestation is to evaluate the effect of posture change from the supine to sitting position and before and after passive leg raising on maternal functional hemodynamics in pregnant women at 35-37 weeks' gestation and to compare the changes in pregnancies that subsequently developed PE and GH to those who remained normotensive.

Methods

The data for this study were derived from prospective screening for adverse obstetric outcomes in women attending for their routine hospital visit in the third trimester of pregnancy at King's College Hospital and Medway Maritime Hospital, Kent, between March 2015 and December 2015. This visit, which is held at 35^{+0}-37^{+6} weeks' gestation, included recording of maternal characteristics and medical history, ultrasonographic estimation of fetal weight and measurement of maternal cardiovascular parameters. Gestational age was determined by the measurement of fetal crown-rump length at 11-13 weeks or the fetal head circumference at 19-24 weeks.[8,9]

During the study period all women with singleton pregnancies and no reported PE at the time of the routine third trimester clinic were approached and 3,013 (75.1%) of 4,011 agreed to participate in the study. Written informed consent was obtained from the women agreeing to participate in a study on adverse pregnancy outcome, which was approved by the Ethics Committee of each participating hospital. In this publication we present the results of the effect of different postures on maternal cardiovascular parameters. The patients included in the study were all pregnancies resulting in live birth of phenotypically normal babies and were part of our previous publications.[4,5]

Data on pregnancy outcome were collected from the hospital maternity records or the general medical practitioners of the women. The definitions of PE were those of the International Society for the Study of Hypertension in Pregnancy.[10] The obstetric records of all women with pre-existing or pregnancy associated hypertension were examined to confirm if the condition was chronic hypertension, PE or GH.

Maternal cardiovascular function

Cardiovascular function was assessed using a non-invasive, bioreactance method (NICOM, Cheetah Medical Ltd, Maidenhead, Berkshire, UK).[12] Four dual-surface electrodes were applied across the maternal thorax and after 15 minutes of rest in the supine position, whilst the fetal scan is being carried out. First, NICOM recordings were made with the patient in the supine position on a hospital couch for five minutes, second, the patient actively turned to the left lateral position and recordings were made for five minutes, third, the end of the couch was raised by the operator so that there was passive raising of the legs to 45^{o} from the horizontal and recordings were made for three minutes, and fourth, the patient actively moved to the sitting position and recordings were then made for five minutes.

The signal-processing unit of the system determines the relative phase shift of electrical current between the input signal relative to the output signal; the phase shift occurs due to instantaneous changes in blood flow in the aorta. Cardiac output is subsequently estimated as the product of stroke volume and heart rate and total peripheral resistance is calculated as a product of cardiac output and mean arterial pressure (MAP). The measurements of cardiac output, stroke volume and total peripheral resistance were divided by the participant's body surface area (weight x height^2) and expressed as indices to achieve normalization for body size. This operator-independent technology has been validated both in non-pregnant and pregnant populations.[12,13]

Statistical analysis

The measurements of cardiac index, stroke volume index, heart rate, total peripheral resistance index, MAP, obtained in the last 120 seconds of recording in supine, left lateral and sitting positions were considered. In the case of passive leg raising position the last 90 seconds of recording were considered. Wilcoxon signed rank test was used to compare the

values of these cardiovascular parameters in different postures within each outcome group. Mann Whitney-U test was used to compare the observed values of these cardiovascular parameters assessed in each of the four postures between the outcome groups. One-way ANOVA was used to compare the hemodynamic response in these cardiovascular parameters to a change from the supine to the sitting position and from the left lateral to the passive leg raising position between the outcome groups.

The statistical software package SPSS 22.0 (SPSS Inc.,Chicago, IL) and Medcalc (Medcalc Software, Mariakerke, Belgium) were used for all data analyses.

Results

Maternal characteristics of the study population have been reported in a previous publication.[4] Birth outcomes are presented in Table 1.

Effect of posture change from supine to sitting

In normotensive pregnancies, the hemodynamic response to a change from the supine to the sitting position was increase in cardiac index, stroke volume index and MAP, no significant change in heart rate, and decrease in total peripheral resistance index (Table 2, Figure 1). With regard to the effect of maternal size, the change in cardiac index, stroke volume index and total peripheral resistance index in response to a change from the supine to the sitting position was not significantly different between different BMI groups; but in women with BMI >25 Kg/m^2 the increase in MAP was less pronounced (Table 3, Figure 2).

In pregnancies that subsequently developed PE, there was a lesser increase in cardiac index and stroke volume index and there was a reduction, rather than an increase, in MAP,

in response to the postural change (Table 2, Figure 1). In cases of GH, there was a lesser increase in cardiac index and a lesser reduction in total peripheral resistance index (Table 2, Figure 1).

Effect of passive leg raising

In normotensive pregnancies, the hemodynamic response to passive leg raising was increase in cardiac index, stroke volume index and MAP and decrease in heart rate and total peripheral resistance index (Table 2, Figure 3). With regard to the effect of maternal size, the change in response to passive leg raising in cardiac index, stroke volume index, heart rate and MAP was not significantly different between the BMI groups (Table 3, Figure 4).

In pregnancies that subsequently developed PE and GH there were no significant hemodynamic findings in response to passive leg raising, except in women with GH there was a reduction in total peripheral resistance index (Table 2, Figure 1).

Discussion

Principle findings of this study

In normotensive singleton pregnancies at 35-37 weeks' gestation, both change from the supine to the sitting position and passive leg raising were associated with increase in cardiac index and stroke volume index and decrease in total peripheral resistance index; there was no significant change in heart rate and a small increase in MAP. Increased body mass index was associated with lower stroke volume index, cardiac index and higher heart rate, MAP and total peripheral resistance index. The degree of positional change in cardiac index,

stroke volume index, MAP and total peripheral resistance index did not increase with body mass index.

In pregnancies that subsequently developed PE and GH, compared to normotensive pregnancies, cardiac index and stroke volume index were lower and total peripheral resistance index was higher. In general, change from the supine to the sitting position and passive leg raising were associated with similar but less marked changes in cardiovascular parameters as in normotensive pregnancies. It is possible that women that develop PE or GH have impaired preload reserve and are therefore potentially vulnerable to fluid overload and cardiac failure. This is compatible with the observation that in established late PE there is impaired myocardial contractility and diastolic dysfunction.[14] Another factor that may contribute to a dampened response to postural change in pregnancies that develop PE is increased tone or stiffness of the veins [15,16] resulting in reduced venous capacitance and thus decrease in venous return.

Strengths and limitations

The study used an automated non-invasive cardiac monitor to provide accurate measurement of cardiovascular function in a large cohort of pregnant women attending routine assessment of fetal growth and wellbeing. However, in the cases that developed PE or GH the observed changes in cardiac parameters in response to postural change were not significant presumably because of the relatively small number of cases that were examined.

Comparison with previous studies

In normotensive pregnancies a change from the supine to the sitting position is associated with increase in cardiac index and stroke volume index and decrease in total peripheral resistance index. These findings are the opposite to what we expected because such

postural change would reduce preload. It is possible that in the supine position in late pregnancy there is reduced venous return from uterine compression of the superior vena cava and this is reversed upon assuming a sitting position with consequent increase in stroke volume and cardiac output and reactive increase in peripheral resistance to maintain MAP. Our results are consistent with those of a previous study, which also found an increase in cardiac output in a sitting position.[17]

Our findings further add to the contentious issue regarding the behavior of maternal cardiovascular function to positional change in the third trimester. Our results are not comparable to two landmark publications on maternal physiology related to position as different methods were used for assessing maternal cardiac function and different positional changes were evaluated. Easterling *et al.* studied 16 healthy women at 35-40 weeks' gestation showing that a change from left lateral to sitting position was associated with a significant decrease in cardiac output and stroke volume, and an increase in total peripheral resistance.[18] Bene *et al.* evaluated maternal cardiac function using parasternal echocardiography at 32-34 weeks' gestation in 16 healthy women and showed that a change from left lateral to standing position did not alter the cardiac output, and suggested the observed reduction in preload on standing was diminished in the third trimester by blood volume expansion and increased venous return on standing due to reduction in the elasticity and distensibility of lower limb veins.[19] Clark *et al.* evaluated cardiac output using the invasive Swan-Ganz technique in 10 normotensive women at 36-38 weeks' gestation and showed that position change from supine to sitting was associated with an increase in cardiac output and stroke volume, and a decrease in total peripheral resistance.[20] Such findings are in agreement with our data.

The response to passive leg raising in the third trimester also appears to be a controversial issue. In our normotensive group passive leg raising was associated with increase in cardiac index and stroke volume index and decrease in total peripheral resistance index with no

significant change in heart rate and a small increase in MAP. Our results are in agreement with those of a study of 108 healthy pregnant women at 22-24 weeks' gestation and 54 non-pregnant women which reported that, in both groups, passive leg raising was associated with increase in stroke volume and decrease in systemic vascular resistance.[21] In contrast, a study in 47 healthy pregnant women at around 39 weeks' gestation reported that passive leg raising was associated with a significant decrease in heart rate and no change in cardiac index, stroke volume or systemic vascular resistance.[22] The differences here could be due to the difference in gestational age at assessment. At 39 weeks' gestation, fetal head engagement and size of uterus may prevent left lateral position in overcoming aorto-caval compression. A longitudinal study examined 98 healthy pregnant women for 3-5 times during 20-40 weeks' gestation. Passive leg raising was associated with a decrease in heart rate, cardiac output and MAP throughout the second half of pregnancy, total peripheral resistance was reduced up to 32 weeks and increased slightly thereafter, whereas stroke volume was increased up to 32 weeks and decreased thereafter.[23]

Our data show that despite indexing cardiac parameters for body surface area, increased body mass index is associated with lower stroke volume index, cardiac index and higher heart rate, mean arterial pressure and total peripheral resistance index in women who remained normotensive. This is pertinent given the findings from our previous paper wherein women with PE and GH were of significantly increased weight, and showed a similar pattern of hemodynamics.[5] This is also in keeping with another study that showed that morbidly obese women had an adverse hemodynamic profile compared to women of normal weight.[24]

Conclusions

Paradoxically, in late third trimester normal pregnancies both change from the supine to the sitting position and passive leg raising may result in increase in preload with consequent increase in cardiac index and stroke volume index and decrease in total peripheral

resistance index. In pregnancies that develop PE or GH the effects of postural change on cardiovascular parameters are similar but less marked than in normotensive pregnancies.

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Figure legends

Figure 1. Maternal cardiovascular parameters in the supine and sitting positions in pregnancies that subsequently developed PE (red), compared to normotensive pregnancies (black). Circles represent the mean and whiskers 95% confidence intervals for the mean.

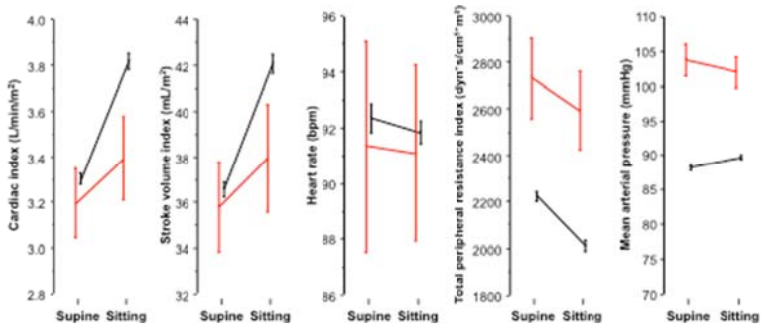

Figure 1

Figure 2. Maternal cardiovascular parameters in the supine and sitting positions in normotensive pregnancies according to body mass index (blue: BMI <25 Kg/m^2; green: BMI 25-29.9 Kg/m^2; black: BMI ≥30 Kg/m^2). Circles represent the mean and whiskers 95% confidence intervals for the mean.

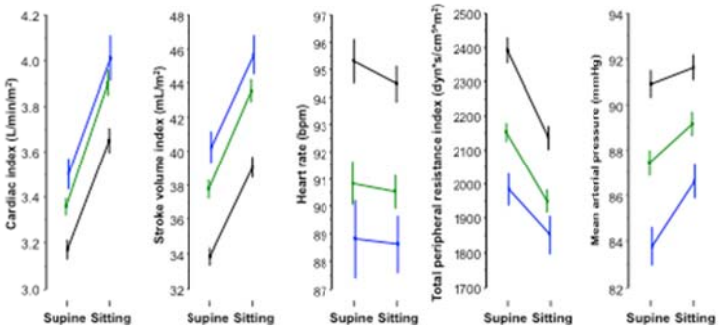

Figure 2

Figure 3. Maternal cardiovascular parameters in the left lateral position before and after passive leg raising in pregnancies that subsequently developed PE (red), compared to normotensive pregnancies (black). Circles represent the mean and whiskers 95% confidence intervals for the mean.

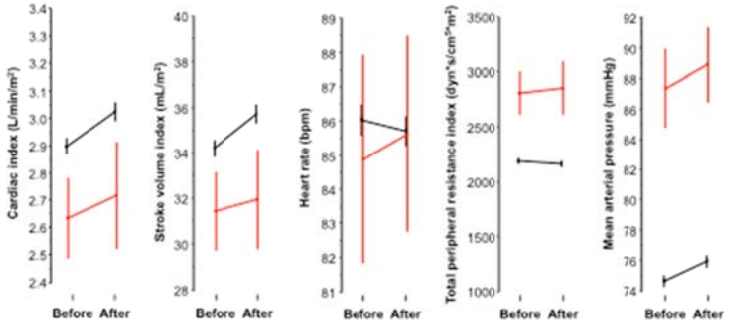

Figure 3

Figure 4. Maternal cardiovascular parameters in the left lateral position before and after passive leg raising in normotensive pregnancies according to body mass index (blue: BMI <25 Kg/m^2; green: BMI 25-29.9 Kg/m^2; black: ≥30 Kg/m^2). Circles represent the mean and whiskers 95% confidence intervals for the mean.

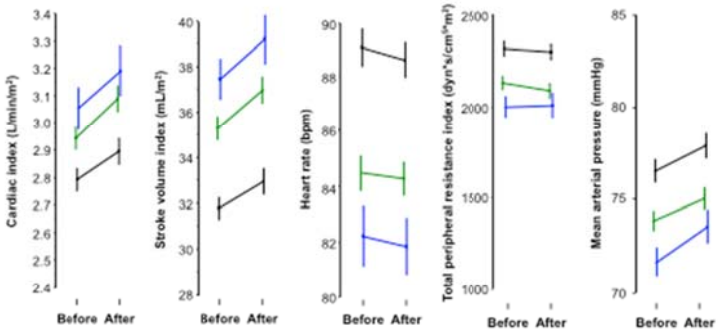

Figure 4

Table 1. Birth outcomes of the population.

Characteristics	**Normal (n=2,586)**	**Preeclampsia (n=66)**	**Gestational hypertension (n=112)**
Mode of delivery			
Vaginal delivery	1,612 (62.3)	29 (43.9)	49 (43.8)
Instrumental delivery	337 (13.1)	15 (22.7)	25 (22.3)*
Cesarean section	637 (24.6)	22 (33.3)	38 (33.9)
Gestational age at delivery (wks), median (IQR)	40.0 (39.1-40.9)	39.6 (38.1-40.4)*	39.7 (38.9-40.6)
Birthweight (g), median (IQR)	3,490 (3,233-3,775)	3,307 (2,896-3,572)*	3,255 (2,932-3,670)*
Birthweight centile, median (IQR)	52.9 (31.5-75.8)	36.7 (16.6-70.4)*	30.9 (14.0-67.1)*
Apgar at 5 minute, median (range)	10 (1-10)	10 (6-10)	10 (8-10)
Apgar at 10 minutes, median (range)	10 (1-10)	10 (8-10)	10 (9-10)

Numerical variables are presented in median (inter-quartile range or range) and categorical variables are presented in number (percentage).

Comparisons between outcome groups were by Chi-square or Fisher exact test for categorical variables and Mann Whitney-U test for continuous variables, with post-hoc Bonferroni correction (*P<0.025).

Table 2. Difference of maternal cardiovascular parameters between postures.

Measured parameters	Posture	Unaffected (n=2,586)		Preeclampsia (n=66)		Gestational hypertension (n=112)	
		Comparisons	Differences	Comparisons	Differences	Comparisons	Differences
Supine vs Sitting							
Cardiac index (L/min/m^2)	Supine	3.300 (2.860-3.730)	12.1%¶	3.180 (2.775-3.640)	5.5%♯	3.060 (2.760-3.528)*	5.2%♯
	Sitting	3.700 (3.170-4.350)		3.355 (2.865-3.788)*		3.220 (2.858-3.640)*	
Stroke volume index (mL/m^2)	Supine	36.0 (30.0-42.0)	13.9%¶	35.5 (29.8-40.1)	3.5%♯	34.2 (28.4-39.9)*	8.3%
	Sitting	41.0 (28.8-41.5)		36.8 (32.2-45.0)*		37.0 (29.7-42.0)*	
Heart rate (bpm)	Supine	91.5 (83.5-100.0)	0.2%	91.2 (79.9-100.8)	0.1%	91.3 (83.1-98.0)	-0.9%
	Sitting	91.7 (84.5-98.8)		91.3 (81.5-101.3)		90.5 (83.3-98.8)	
Total peripheral resistance index (dyn*s/cm^5*m^2)	Supine	2,137 (1,846-2,493)	-9.6%¶	2,629 (2,214-3,082)*	-5.0%	2,500 (2,200-2,953)*	-0.8%♯
	Sitting	1,933 (1,604-2,327)		2,498 (2,114-2,902)*		2,480 (2,204-2,955)*	
Mean arterial pressure (mmHg)	Supine	88.0 (83.0-94.0)	1.1%¶	103.5 (97.0-103.5)*	-1.4%♯	98.0 (92.0-105.8)*	3.6%
	Sitting	89.0 (84.0-96.0)		102.0 (95.8-107.0)*		101.5 (95.0-108.0)*	
Left lateral vs passive leg raising							
Cardiac index (L/min/m^2)	Left lateral	2.840 (2.410-3.340)	3.4%¶	2.600 (2.168-3.003)**	4.5%	2.665 (2.228-3.183)	4.5%
	PLR	2.937 (2.441-3.501)		2.717 (2.150-3.194)**		2.785 (2.312-3.243)**	
Stroke volume index (mL/m^2)	Left lateral	33.5 (27.7-39.7)	3.3%¶	30.5 (25.6-37.0)**	1.3%	33.2 (28.0-37.7)	-0.7%
	PLR	34.6 (28.5-41.6)		30.9 (25.1-38.6)**		32.9 (27.1-39.5)	
Heart rate (bpm)	Left lateral	86.0 (78.0-93.7)	-0.4%¶	85.0 (75.0-94.3)	-0.8%	86.8 (78.4-93.3)	-1.9%
	PLR	85.7 (78.3-92.7)		84.3 (76.6-95.3)		85.2 (77.8-92.0)	
Total peripheral resistance index	Left lateral	2,078 (1,749-2,537)	-1.1%¶	2,783 (2,218-3,293)**	-7.0%	2,470 (2,089-2,992)**	-4.8%♯

(dyn*s/cm^5*m^2)	PLR	2,055 (1,682-2,529)		2,588 (2,242-3,401)**		2,352 (2,089-2,992)**	
Mean arterial pressure (mmHg)	Left lateral	74.0 (68.0-80.0)	1.4%¶	86.5 (78.8-95.0)**	2.3%	84.0 (79.0-89.8)**	0.0%
	PLR	75.0 (69.0-82.0)		88.5 (82.0-97.0)**		84.0 (78.3-92.8)**	

Data presented in median (interquartile range); PLR = passing leg raising

1. Comparisons of maternal cardiovascular parameters between different postures within each outcome group were by Wilcoxon signed rank test, with Bonferroni correction (¶P<0.0125).
2. Comparisons of maternal cardiovascular parameters between the outcome groups in supine and sitting postures were by Mann Whitney test, with Bonferroni correction (*P<0.025).
3. Comparisons of maternal cardiovascular parameters between the outcome groups in left lateral and passive leg raising postures were by Mann Whitney test, with Bonferroni correction (**P<0.025).
4. Comparisons of the change from supine to sitting and from left lateral to passive leg raising in maternal cardiovascular parameters between the outcome groups were by one-way ANOVA (♯P<0.05).

Table 3. Difference of maternal cardiovascular parameters between postures in unaffected women according to body mass index (BMI).

Measured parameters	Posture	BMI <25 Kg/m^2 (n=395)		BMI 25-29.9 Kg/m^2 (n=1,153)		BMI ≥30 Kg/m^2 (n=1,038)	
		Comparisons	Differences	Comparisons	Differences	Comparisons	Differences
Supine vs Sitting							
Cardiac index (L/min/m^2)	Supine	3.490 (3.030-3.890)	11.2%¶	3.330 (2.925-3.775)*	14.7%¶	3.170 (2.730-3.528)*	11.8%¶
	Sitting	3.880 (3.340-4.650)		3.820 (3.240-4.505)		3.545 (3.080-4.130)*	
Stroke volume index (mL/m^2)	Supine	39.7 (33.3-46.0)	12.2%¶	37.0 (31.5-43.0)*	15.3%¶	33.0 (28.0-39.3)*	15.2%¶
	Sitting	44.5 (37.5-52.3)		42.7 (35.8-50.0)*		38.0 (32.0-44.3)*	
Heart rate (bpm)	Supine	87.0 (79.3-98.0)	1.1%	90.0 (82.0-98.3)*	0.6%	94.5 (86.7-103.0)*	-0.2%
	Sitting	88.0 (81.3-96.0)		90.5 (83.3-97.6)*		94.3 (87.5-101.3)*	
Total peripheral resistance index (dyn*s/cm^5*m^2)	Supine	1,908 (1,669-2,216)	-6.8%¶	2,096 (1,827-2,399)*	-11.5%¶	2,293 (1,957-2,714)*	-9.5%¶
	Sitting	1,778 (1,483-2,095)		1,854 (1,555-2,265)*		2,075 (1,744-2,443)*	
Mean arterial pressure (mmHg)	Supine	84.0 (79.0-89.0)	2.4%¶	87.0 (82.0-93.0)*	2.3%¶♯	91.0 (85.0-97.0)*	0%♯
	Sitting	86.0 (81.0-91.0)		89.0 (83.0-95.0)*		91.0 (86.0-97.0)*	
Left lateral vs passive leg raising							
Cardiac index (L/min/m^2)	Left lateral	2.970 (2.530-3.550)	6.7%¶	2.890 (2.470-3.380)**	4.8%¶	2.710 (2.310-3.200)**	3.4%¶
	PLR	3.169 (2.561-3.745)		3.030 (2.518-3.559)		2.802 (2.322-3.355)**	
Stroke volume index (mL/m^2)	Left lateral	37.0 (31.0-43.0)	4.4%¶	34.5 (29.0-40.7)**	3.5%¶	31.0 (25.7-36.3)**	2.3%¶
	PLR	38.6 (31.6-45.6)		35.7 (30.1-42.8)**		31.7 (26.1-38.2)**	
Heart rate (bpm)	Left lateral	81.7 (74.0-90.0)	-0.4%¶	84.3 (76.5-91.7)**	-0.4%	89.0 (81.5-96.7)**	0%
	PLR	81.3 (74.0-89.3)		84.0 (77.0-91.0)**		89.0 (81.9-95.3)**	

Total peripheral resistance index ($dyn*s/cm^5*m^2$)	Left lateral	1,874 (1,629-2,298)	-0.3%¶	2,020 (1,707-2,460)**	-2.0%¶	2,222 (1,876-2,665)**	-1.3%
	PLR	1,868 (1,558-2,328)		1,979 (1,636-2,437)**		2,194 (1,814-2,670)**	
Mean arterial pressure (mmHg)	Left lateral	71.0 (67.0-77.0)	2.8%¶	73.0 (68.0-79.0)**	1.4%¶	75.0 (70.0-82.0)**	2.7%¶
	PLR	73.0 (68.0-79.0)		74.0 (69.0-81.0)**		77.0 (70.0-84.0)**	

Data presented in median (interquartile range); PLR = passing leg raising; BMI = body mass index

1. Comparisons of maternal cardiovascular parameters between different postures within each BMI group were by Wilcoxon signed rank test, with Bonferroni correction (¶P<0.0125).
2. Comparisons of maternal cardiovascular parameters between the BMI groups in supine and sitting postures were by Mann Whitney test, with Bonferroni correction (*P<0.025).
3. Comparisons of maternal cardiovascular parameters between the BMI groups in left lateral and passive leg raising postures were by Mann Whitney test, with Bonferroni correction (**P<0.025).
4. Comparisons of the change from supine to sitting and from left lateral to passive leg raising in maternal cardiovascular parameters between the BMI groups were by one-way ANOVA (♯P<0.05).