

Research article

The effect of regular exercise training during pregnancy on postpartum brachial–ankle pulse wave velocity, a measure of arterial stiffness

Ikuno Kawabata ¹✉, Akihito Nakai ¹, Atsuko Sekiguchi ¹, Yuko Inoue ² and Toshiyuki Takeshita ¹

¹ Department of Obstetrics and Gynecology, Nippon Medical School, Tokyo, Japan; ² Inoue Ladies Clinic, Tokyo, Japan

Abstract

The aim of our study was to use brachial–ankle pulse wave velocity (baPWV) measurements to noninvasively assess the effect of exercise training on arterial stiffness in normal pregnant women. Arterial stiffness was assessed at the beginning of the early second trimester of pregnancy and 1 month after delivery in 17 women with normal singleton pregnancies who exercised regularly throughout pregnancy: 81 matched controls were used for comparison. No significant differences were observed in baPWV between the exercise and control groups at the beginning of the second trimester. BaPWV 1 month after delivery (1160.2 ± 109.1 cm·second⁻¹) was significantly higher than that in the early second trimester (1116.7 ± 87.9 cm·second⁻¹) in the control group (indicating increased arterial stiffness), but not in the exercise group (1145.9 ± 88.1 cm/second vs 1122.7 ± 100.2 cm·second⁻¹, respectively: not significant). The results indicated that regular maternal exercise training decreased arterial stiffness in normal pregnant women, which suggests that regular exercise may help prevent hypertensive disorders during pregnancy.

Key words: Brachial–ankle pulse wave velocity, maternal exercise training, arterial stiffness.

Introduction

Pregnancy is associated with maternal physiological changes that require adaptation of the cardiovascular system. Large increases in the plasma volume and cardiac output are observed because of arterial vasodilatation that occurs during normal pregnancy. These cardiovascular adaptations are important for successful outcome of pregnancy (Elvan-Taspinar et al., 2005). Arterial vasodilatation during pregnancy is associated with increased aortic distension (Elvan-Taspinar et al., 2005; Macedo et al., 2008; Poppas et al., 1997). Previous reports have indicated that increased arterial stiffness during pregnancy causes several disorders such as pregnancy-induced hypertension (PIH) and fetal growth restriction (Macedo et al., 2008; Oyama-Kato et al., 2006).

A decrease in arterial function with advancing age is considered to be a part of aging and is reflected in elevated systolic blood pressure and decreased arterial compliance (Folkow and Svanborg, 1993). Central arterial stiffness is increased in coronary artery disease and myocardial infarction (Gatzka et al., 1998). An increase in arterial stiffness in coronary artery disease can lead to myocardial ischemia because of increased myocardial oxygen demand and decreased coronary perfusion.

Regular exercise training has beneficial effects on

these arterial disorders (Edwards et al., 2004; Tanaka et al., 2000; Vaitkevicius et al., 1993). Tanaka et al. reported that the arterial compliance in middle-aged and older men who performed aerobic training for 12 weeks was lower than that in age-matched sedentary controls (Tanaka et al., 2000). Edwards et al. suggested that endurance exercise training decreases systemic arterial stiffness in patients with coronary artery disease.

Physical activity during pregnancy has been shown to improve health outcomes for both the mother and the fetus. According to the current American College of Obstetrics and Gynecology (ACOG) guidelines, all pregnant women are encouraged to be physically active for at least 30 minutes on most days of the week in the absence of medical or obstetrical contraindications (ACOG: Committee opinion 2002). Some evidence suggests that physical activity is associated with shorter active labor and decrease in back pain, insomnia and anxiety (American College of Sports Medicine, 2006; Clapp, 1990a; Goodwin et al., 2000). Fetal outcomes improved by maternal physical activity include higher Apgar scores and increased fat-free mass at birth (Clapp, 1990b). In addition, excessive gestational weight gain is associated with numerous unfavorable pregnancy outcomes such as gestational diabetes mellitus, pregnancy-related hypertension, complications of labor and delivery, and macrosomia (Beyerlein et al., 2009; Gunderson et al., 2000). Physical activity during pregnancy was associated with a significantly lower average gestational weight gain in the intervention groups compared with that in the control groups (Streuling et al., 2011). Although there has been a dramatic increase in the number of pregnant women engaged in physical activity, no studies have evaluated the effect of exercise training on arterial function in pregnant women.

Researchers have developed an automated device for measuring brachial–ankle pulse wave velocity (baPWV), which shows a good correlation with aortic PWV, by evaluating the distensibility of brachial and tibial arteries (Sugawara et al., 2005; Yamashina et al., 2002). BaPWV, an indicator of arterial stiffness, depends on the functional and structural features of arteries, which are related to their intrinsic elastic properties (Yamashina et al., 2002). This method is noninvasive and rapid, and shows good repeatability (Yamashina et al., 2002). In addition, its simplicity makes it suitable for screening of large populations (Oyama-Kato et al., 2006).

Oyama-Kato et al. (2006) reported longitudinal changes in baPWV from the first trimester to 1 month after delivery in normal pregnancies. BaPWV was signifi-

cantly lower in the second trimester than in the first trimester. BaPWV 1 month after delivery tended to be slightly lower than that in the third trimester. However compared with the second trimester, baPWV was significantly higher in the third trimester and at 1 month after delivery. In addition, baPWV value in the pregnancy induced hypertension (PIH) group increased throughout pregnancy, suggesting that vascular stiffness in the PIH group was significantly higher than that in normal pregnancy (Oyama-Kato et al., 2006). Elvan-Taspinar et al. (2005) reported that there was a significant relationship in PWV with both birth weight centiles and catch-up growth after birth. PWV seems to be useful for assessing the vasculature both during pregnancy and postpartum.

Although several studies have suggested that exercise has some beneficial effects during pregnancy, little is known about the effect of maternal exercise on arterial function. Our aim was to determine the effects of maternal exercise on arterial stiffness using baPWV measurements.

Methods

Study population

In total, 98 healthy pregnant women with normal singleton pregnancies, who were aged between 25 and 41 years, were studied at Inoue Ladies Clinic in Tokyo from January through June 2008. All subjects provided written informed consent to clinical characteristics of this study population are summarized in Table 1. We excluded subjects with a history of preterm delivery more than two miscarriages and persistent bleeding after 12 weeks of gestation. We also excluded subjects with hypertensive conditions whose arterial blood pressure was higher than 140/90 mmHg at rest during 8-12 weeks of gestation. Subjects with a history of smoking, those who had ever been diagnosed as having hypertension, hyperlipidemia, diabetes mellitus, and other chronic disease, and those who were regularly taking regular medication including hormonal and any other medicines, were excluded on the basis of responses to a questionnaire. In addition, we excluded obesity (BMI >25), low body weight (BMI <18), and eating disorder. All subjects were sedentary, and did not participate regularly in a sport before pregnancy. Gestational age was calculated on the basis of the last menstrual period, a reliable menstrual history, and/or an ultrasound examination before 10 weeks of gestational age. Both the control and exercise groups received similar standard antenatal care; they visited to the clinic every 2-3 weeks until 14 weeks of gestation, once a month until 22 weeks of gestation, every 2 weeks until 36 weeks of gestation, and then once a week until delivery. All subjects underwent routine urinary examination and underwent routine evaluation of arterial blood pressure, body weight, and condition of their pregnancy. If they had any problems, they received suitable care or treatments from their obstetricians or midwives.

Exercise training

Exercise training was conducted at the Inoue Clinic in Tokyo. The exercise group was designed for the pregnant

women who wished to perform maternal exercise program. A maternal exercise program was initiated for all subjects in the exercise group. Subjects started aerobic exercise after 16 weeks of gestation. Although overall exercise performance varied widely between the subjects, the women recruited into the exercise group continued to perform aerobic exercise vigorously three or more times each week for at least 60 minutes per session. Each session started with 5-minutes warm up, followed by 35 minutes of aerobic dance, including cool down. This was followed by 15 minutes of strength training. The last 5 minutes included stretching, relaxation and body awareness exercises. The aerobic dance routine included low-impact exercise but no jumping or running. We checked maternal and fetal heart rates, maternal arterial blood pressure and temperatures, and the frequency of uterine contractions before and after exercise. The subjects stopped exercising when they felt fatigued or noticed increased frequency of their uterine contractions. The intensity of the maternal exercise program was decreased to maintain a heart rate below 150 beats per minute and a body temperature below 38°C. Therefore, the perceived exertion was rated as fairly light. All training programs were supervised by exercise instructors. Healthy pregnant women who did not have regular sustained exercise during pregnancy were recruited as the control group.

Pulse wave analysis

An automatic device (Form PWV/ABI; Colin Medical Technology, Komaki, Japan), that records pulse waves and automatically calculates baPWV, as previously described and validated (Bank et al., 1990; Yamashina et al., 2002) was used to measure baPWV. The device records PWV, arterial blood pressure, electrocardiogram, and heart sounds simultaneously. Measurements were made with the subjects in the supine resting position in a quiet, temperature-controlled room after at least 10 minutes of rest in the supine position. Cuffs wrapped on both of the upper arms and ankles were used to record pressure waves, electrodes placed on both wrists were used to record the electrocardiogram, and a microphone placed on the left edge of the sternum was used to record heart sounds. Pressure waveforms at the upper arms and ankles were recorded for a sampling time of 10 seconds, with automatic gain analysis and quality adjustment. Sufficient waveform data were obtained in this recorded sample. The characteristic points of waveforms were determined automatically according to the phase velocity theory. Components more than 5 Hz were recorded, and the initial rise in the waveforms was determined. The time interval between the arm and ankle waves (ΔT_{ba}) was determined as the time interval between the initial rise in the waveforms of the brachial and tibial arterial pressures. The distance between the baPWV sampling points was calculated automatically on the basis of body height. The equation $L_a = 0.8129 \times \text{height} + 12.328$ (all values for length and height were in centimeters) was used to estimate the length from the aortic valve to the ankle (L_a). The equation $L_b = 0.2195 \times \text{height} - 2.074$ was used to estimate the length from the aortic valve to the arm (L_b). The equation $\text{baPWV} = (L_a - L_b) / \Delta T_{ba}$ was used to

Table 1. Characteristics of subjects. Data are expressed as means (\pm standard deviation).

	Exercise group	Control group
n	17	81
Age, years	33.4 (2.85)	32.1 (4.0)
Nulliparity, number (%)	8 (47.1)	33 (40.7)
Family history of hypertension, number (%)	5 (29.4)	18 (22.2)
Height, m	1.58 (.06)	159.2 (5.7)
Body weight before pregnancy, kg	51.2 (5.3)	51.5 (7.0)
Body mass index before pregnancy, kg·m ⁻²	20.6 (2.00)	20.3 (2.4)
Weight gain during pregnancy, kg	10.4 (3.9)	10.2 (3.9)
Gestational age at delivery, week	39.1 (1.5)	39.2 (1.17)
Cesarean delivery, number (%)	3.0 (17.6)	15.0 (18.5)
Blood loss during delivery, ml	471.6 (346.5)	462.3 (348.1)
Neonatal birth weight, g	2988.3 (454.3)	3009.4 (396.6)

All data between the two groups were no significant differences.

estimate baPWV. The PWV was used to automatically and simultaneously measure bilateral baPWV as well as brachial and ankle arterial brachial blood pressure both of which were used in our analysis. BaPWV was measured in all subjects when they visited the outpatient clinic for prenatal or puerperal care. BaPWV of the exercise group were measured before physical activity.

Statistical analysis

The data are presented as means \pm standard deviations. Reported measures one-way Statistical analysis was performed using a repeated-measures one-way analysis of variance (Statview Corp, San Francisco, CA, USA) was used to perform statistical analysis. The Student's *t*-test, paired *t*-test, and the χ^2 test were used to perform comparisons between the two groups. Differences were considered significant at $p < 0.05$.

Results

Recordings were successfully obtained from all subjects, and all of them tolerated the studies well. No subjects develop preeclampsia, gestational hypertension or other diseases that could interfere with participation in the exercise program.

The characteristics of the women participating in the study are given in Table 1. Among the women, 17 (17.3%) who underwent exercise vigorously three or more times each week throughout their pregnancies were included in the exercise group, and 81 (82.3%) were included in the control group. Between the two groups, there were no significant differences in the indices thought to be associated with baPWV such as maternal age, height, body weight, body mass index, and weight

gain during pregnancy. In addition, there were no differences in the eating habits between the two groups.

Table 2 shows the physical characteristics at examination. In the exercise group, the first examination of baPWV was performed at 14.1 ± 1.66 weeks of gestation, and the second at 33.0 ± 1.76 days after delivery. In the control group, the first examination of baPWV was performed at 14.0 ± 1.21 weeks of gestation and the second at 34.1 ± 2.32 days after delivery. The exercise and control groups did not differ with regard to time of examination, height, weight, systolic blood pressure, and diastolic blood pressure.

Table 2. Physical characteristics at the examinations. Data are expressed as means (\pm standard deviation).

	Exercise group	Control group
n	17	81
First examination (early second trimester)		
SBP (mmHg)	107.1 (9.3)	110.8 (12.3)
DBP (mmHg)	63.2 (9.0)	65.4 (9.5)
Body weight (kg)	52.1 (5.6)	51.2 (9.1)
Second examination (after delivery)		
SBP (mmHg)	110.3 (11.9)	114.2 (11.7)
DBP (mmHg)	67.9 (8.5)	68.9 (8.2)
Body weight (kg)	54.8 (5.8)	54.4 (6.9)

GA: gestational age, SBP: systolic blood pressure, DBP: diastolic blood pressure. All data between the two groups were no significant differences.

Table 3 shows the changes in baPWV during pregnancy from the first examination (early second trimester) to the second examination (about 1 month after delivery). Compared with baPWV at the first examination, there were no significant differences in baPWV at 1 month after delivery on either side between the two groups.

Table 3. Changes in baPWV. Data are expressed as means (\pm standard deviation).

	First Examination (cm·second ⁻¹) (early second trimester)	Second Examination (cm·second ⁻¹) (after delivery)
Exercise group (n=17)		
Right side	1122.7 \pm 98.9	1137.2 (92.7)
Left side	1122.7 \pm 104.9	1154.8 (87.6)
Average	1122.7 \pm 100.2	1145.9 (88.1)
Control group (n=81)		
Right side	1114.3 \pm 92.1	1158.5 (113.4) **
Left side	1119.1 \pm 89.9	1161.9 (110.4) **
Average	1116.7 \pm 87.9	1160.2 (109.1) **

** $p < 0.01$ for the difference between the first and second examination.

Discussion

The present study showed that regular maternal exercise training decreased arterial stiffness in pregnancy. BaPWV of normal pregnant women not undergoing exercise was shown to increase significantly after delivery. In contrast, there was no significant change in baPWV between the early second trimester and 1 month after delivery in women who performed aerobic training during pregnancy.

PWV reflects tunica media function and is affected by histopathological changes in arterial structure (Sugawara et al., 2005). BaPWV, an indicator of arterial stiffness, depends on the functional and structural features of arteries, which are related to their intrinsic elastic properties. Elevated arterial blood pressure accelerates arterial smooth muscle hyperplasia and hypertrophy as well as collagen synthesis, thereby increasing arterial stiffness (Matsui et al., 2004).

During normal pregnancy, plasma volume expands as a result of arteriolar vasodilatation, and arterial blood pressure falls (Dukekot et al., 1993; Mabie et al., 1994; Mashini et al., 1987; Robson et al., 1989). In contrast, cardiac output increases by 40%-50% of nonpregnant values. Decrease arterial stiffness is associated with a decrease in peripheral vascular resistance and generalized vasodilatation (Tanaka et al., 2000; Vaitkevicius et al., 1993).

Regular physical activity provides substantial health benefits by decreasing the risk of cardiovascular diseases (Blair et al., 1995; Miura et al., 2008; Paffenbarger et al., 1983). Exercise training is associated with decreased arterial stiffness and increased compliance both in animals and in healthy humans (Edwards et al., 2004; Munir et al., 2008). Aerobic walking exercise 4-6 days per week for 12 weeks increases measures of central arterial compliance (inverse of stiffness) in middle-aged and older men (Tanaka et al., 2000). Endurance exercise training, consisting of treadmill walking, stationary cycling, and upper body ergometry, three times per week for 12 weeks also decreases systemic arterial stiffness in patients with coronary artery disease (Yamashina et al., 2002).

The ACOG guidelines recommend that all pregnant women be encouraged to be physically active for at least 30 minutes on most days of the week, in the absence of medical or obstetrical contraindications (ACOG: Committee opinion, 2002). Physical activity during pregnancy has been shown to improve health outcomes for both the mother and the fetus. Some evidence suggests that physical activity is associated with a shorter active labor and decrease in back pain, insomnia, anxiety, and excessive gestational weight gain (American College of Sports Medicine, 2006; Beyerlein et al., 2009; Clapp, 1990b; Goodwin et al., 2000; Gunderson et al., 2000). In our study, the women recruited into the exercise group continued to perform aerobic exercise vigorously three or more times per week for at least 60 weeks. Although overall exercise performance varied widely between the subjects, our results for the exercise group showed a decrease in arterial stiffness at 1 month after delivery. These

results are similar to those from previous studies (Tanaka et al., 2000; Yamashina et al., 2002), suggesting that regular exercise training has beneficial effects on arterial function.

Previous studies have demonstrated that in normal pregnancies, baPWV decreases significantly during the second trimester, increases during the third trimester until immediately after delivery, and then decreases slightly at 1 month after delivery (Macedo et al., 2008; Oyama-Kato et al., 2006). A study (Oyama-Kato M et al., 2006) assessed the longitudinal changes of baPWV during pregnancy. They reported that baPWV at 1 month after delivery was significantly higher than that in the second trimester, reflecting the increase in baPWV during pregnancy. According to the previous reports, we assumed that comparison of baPWV in the early second trimester and at 1 month after delivery would reflect the effects of maternal exercise on baPWV. Our results showed that baPWV increased in normal pregnant women not undergoing exercise training, which are consistent with the results of these previous studies, indicating arterial stiffness increases during pregnancy. In the postpartum period, there were significant differences in baPWV between the exercise and control groups; however, no differences in baPWV between the groups were detected in the second trimester. The differences were assumed to be caused by the effect of exercise, considering that the other medical conditions in both groups that could influence baPWV were similar.

A flaw in the design of our study was the two study groups had an unequal number of subjects. Thirty-three pregnant women participated in our exercise training, but 16 women (48.5%) performed aerobic exercise only one or two times each week or resigned. Therefore, these subjects were excluded from our study. The remaining 17 pregnant women (51.5%) who underwent exercise vigorously three or more times each week throughout their pregnancies were included in the exercise group. Although the rating of the perceived exertion was fairly light in each exercise session, achieving participation in the exercise training throughout the women's pregnancies without interruption was not an easy task. Healthy pregnant women who were sedentary and did not have regular sustained exercise during pregnancy were recruited as the control group.

Arterial blood pressure increases in PIH because of a lack of appropriate hemodynamic adaptation (Savvidou et al., 2001). In women with PIH, baPWV increases throughout pregnancy and for at least 1 month after delivery, suggesting that vascular stiffness in patients with PIH increases significantly compared with that in normal pregnant women (Oyama-Kato et al., 2006). PIH has a high rate of recurrence, and women with a history of PIH have a higher incidence of chronic hypertension in later life than normotensive pregnant women (Sibai et al., 1991). Furthermore, a recent study demonstrated that increased arterial stiffness during normal pregnancies was associated with lower birth weights independent of mean arterial pressure (Elvan-Taspinar et al., 2005).

Conclusion

In conclusion, we found that regular maternal exercise training decreased arterial stiffness during pregnancy. Although previous studies have shown some beneficial effects of exercise during pregnancy, little is known about its effect on arterial function. Our results demonstrated the beneficial effects of maternal exercise on arterial function and suggested that disturbances in arterial function during pregnancy may be prevented by regular exercise.

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Key points

- Regular maternal exercise training decreased arterial stiffness in normal pregnant women, which suggests that regular exercise may help prevent hypertensive disorders during pregnancy.
- Maternal exercise suggests that disturbances in arterial function during pregnancy may be prevented by regular exercise.

AUTHORS BIOGRAPHY

Ikuno KAWABATA

Employment

Department of Obstetrics and Gynecology, Nippon Medical School, Tokyo, Japan

Degree

MD, PhD

Research interests

Maternal exercise, obstetrical (maternal and fetal) medicine

E-mail: ikawabata8512@nms.ac.jp

Akihito NAKAI

Employment

Department of Obstetrics and Gynecology, Nippon Medical School, Tokyo, Japan

Degree

MD, PhD

Research interests

Maternal exercise, obstetrical (maternal and fetal) medicine

Atsuko SEKIGUCHI

Employment

Department of Obstetrics and Gynecology, Nippon Medical School, Tokyo, Japan

Degree

MD, PhD

Research interests

Maternal exercise, obstetrical (maternal and fetal) medicine, Kampoo treatment

Yuko INOUE

Employment

Inoue Ladies Clinic, Tokyo, Japan

Degree

MD, PhD

Research interests

Maternal exercise, obstetrical (maternal and fetal) medicine

Toshiyuki TAKESHITA

Employment

Department of Obstetrics and Gynecology, Nippon Medical School, Tokyo, Japan

Degree

MD, PhD

Research interests

Sterility, assisted reproductive technology

✉ **Ikuno Kawabata MD**

Tama Nagayama Hospital Department of Obstetrics and Gynecology Nippon Medical School, 1-7-1 Nagayama, Tama-City, Tokyo 206-8512, Japan