DYNAMIC EXERCISE IN HUMAN PREGNANCY

(DYNAMISCHE INSPANNING TIJDENS DE HUMANE ZWANGERSCHAP)

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Chapter 1

INTRODUCTION

In pregnancy the uterus, placenta and fetus constitute a growing mass of tissue with a gradually increasing need for oxygen and substrates. Also muscle activity is associated with an acute and marked increase in metabolic demands. Therefore, the question arises if physiological adaptations are sufficiently adequate to meet the combined demands of exercise and pregnancy, when a woman exercises strenuously during pregnancy.

Until recently, physiological responses to exercise in pregnancy were mainly studied to determine whether or not exercise jeopardizes fetal well-being. In women, the study of fetal responses to maternal exercise is virtually limited to recordings of fetal heart rate. During maternal exercise some investigators observed the occasional occurrence of ominous fetal heart rate patterns suggestive of fetal hypoxia, which disappeared rapidly after termination of the exercise (5; 75). These observations were later dismissed as motion artefacts (102).

Invasive techniques are required to study fetal responses in greater detail. For that reason, such studies are limited to laboratory animals.

Early studies in pregnant sheep showed a reduction in fetal oxygen tension of 18 to 29% during moderately strenuous exercise and a variable reduction in uterine blood flow of 0 to 47% (84). It was later demonstrated that the observed reduction in fetal oxygen tension was largely caused by artefact, because no correction had been made for the rise in body temperature during exercise (84). The observation that uterine blood flow decreases in a linear fashion with exercise intensity and recovers rapidly after exercise could explain much of the variation observed in the early studies (84). It was further demonstrated that uterine blood flow decreases during exercise by a mean maximum of about 25% near the point of exhaustion, but that uterine oxygen uptake is maintained (84). Three compensatory mechanisms were recognized: maternal hemoconcentration (84) distibution of blood flow within the uterus from the muscle to the placenta (66) and increased oxygen extraction (84). In addition, it was found that fetal oxygen tension remains within normal limits and that fetal catecholamine concentrations, blood pressure, cardiac output and cardiac output distribution are not significantly affected by maternal exercise to the point of exhaustion (84). For further details on fetal responses to maternal exercise the reader is referred to a previous review of this subject (84). The cumulative experimental evidence suggests that it is unlikely that even strenuous maternal exercise will jeopardize fetal health. This provides justification for the study of physiological responses to exercise in human pregnancy.

When the exercising muscles were to compete with the pregnant uterus for the flow of blood, oxygen, and substrates that are required for the production of energy, the ability to perform exercise could be reduced. It has been argued that this ability should be reduced in pregnant women because cardiac reserve was assumed to be reduced (122). On the other hand, it has been speculated that pregnancy-induced weight gain might exert a training effect (80,84). Until recently, pregnant women were not subjected to strenuous exercise under controlled experimental conditions, and no data were available to support or refute the hypothesis that pregnancy affects the ability to perform exercise.

This thesis represents an effort to obtain a better understanding of the ability of pregnant women to perform aerobic exercise. It consists of four chapters. Chapter 2 describes a longitudinal study of maximal power and oxygen uptake in pregnant and postpartum women. Because only a limited amount of energy can be produced anaerobically, the ability of a person to perform exercise of longer duration depends largely on the capacity of aerobic energy production. Therefore, maximal oxygen uptake is the best indicator of an individual's ability to perform endurance exercise. It can be measured reliably and reproducibly with little inconvenience to the person tested, except for the strain of maximal exercise. In order to determine the effect of pregnancy weight gain, the women were studied both on the bicycle ergometer (nonweightbearing exercise), and on the treadmill (weightbearing exercise). Chapter 3 reports on the safety aspects relevant to the mother and the fetus: maternal electrocardiogram and blood pressure, uterine contractility, and fetal heart rate. Chapter 4 deals with errors and inaccuracies of estimated values of maximal oxygen uptake in pregnant women. Fetal health concerns have limited most exercise testing during pregnancy to submaximal exercise intensities. However, the validity of the methods that have been used to estimate maximal oxygen uptake from submaximal values has not been determined. Finally, Chapter 5 extensively reviews the literature on physiological adaptations which occur in dynamic exercise and pregnancy, and discusses practical implications and guidelines for women who wish to perform sport activities during pregnancy.

Chapter 2

MAXIMAL AEROBIC EXERCISE IN PREGNANT WOMEN: HEART RATE, OXYGEN UPTAKE, CARBON DIOXIDE OUTPUT AND VENTILATION

2.1 INTRODUCTION

Oxygen uptake at rest increases during pregnancy. The addition of fetal-placental metabolism to maternal oxygen uptake is associated with physiological changes in the maternal cardiovascular system, including a rise in cardiac output and redistribution of blood flow with an increase in uterine perfusion. During physical exercise the cardiovascular system adapts in a similar fashion to the increased oxygen demands of the exercising muscles by an increase in heart rate and stroke volume, and by redistribution of blood flow from the splanchnic bed to the working muscles (112). In pregnant women the oxygen demands of the exercising musculature could compete with those of the products of conception.

Previous studies demonstrated that during exercise in sheep fetal oxygen uptake is well preserved, even near the point of maternal exhaustion (83), despite a marked reduction in uterine blood flow (82). Hemoconcentration during exercise (82), redistribution of blood flow within the uterus from the uterine muscle to the placenta (66), and increased extraction of oxygen by the fetal-placental unit (83) are likely to be effective compensatory mechanisms. These experimental findings make it unlikely that even strenuous maternal exercise will jeopardize fetal health and provide justification for the study of physiological responses to exercise in human pregnancy.

The question whether pregnancy affects the ability to perform physical exercise, has been addressed previously, but has not been answered conclusively (84). On the one hand, it has been suggested that venous return and cardiovascular reserve decline progressively with advancing gestation (121), which may reduce the ability to perform exercise. On the other hand, it could be argued that the progressive weight increase during pregnancy may exert a training effect. In addition, a recent study suggests that pregnancy increases exercise efficiency (35).

Most exercise studies in pregnant women were performed at submaximal levels of exercise only, but the assumptions inherent in the extrapolation of results from submaximal exercise tests to maximal exercise capacity have not been validated for pregnancy (84). A recent study of maximal treadmill exercise indicated that maximal oxygen uptake is lower in pregnant than in nonpregnant women (7). However, not only pregnancy per se but also differences in body

weight, body composition, condition, and motivation between individuals may have affected the outcome of this cross-sectional study. Indeed, a recent longitudinal study failed to demonstrate a significant difference in maximal oxygen uptake between pregnant and postpartum women during bicycle exercise (114). Both studies were performed in the second and early third trimester of pregnancy and thus excluded the time of gestation when changes may be expected to be most pronounced.

In an attempt to determine the effect of pregnancy on the ability of the body to perform aerobic exercise, a longitudinal study was performed of maximal oxygen uptake during bicycle and treadmill tests with rapidly progressing exercise intensities throughout pregnancy and after delivery.

2.2 MATERIAL AND METHODS

Every woman enrolled in the study was investigated at 16, 25, and 35 weeks' pregnancy and 7 weeks after delivery. Heart rate, oxygen uptake, carbon dioxide output, and ventilation were measured at rest and at increasing levels of bicycle and treadmill exercise until maximum aerobic power was reached. Four of the women were also studied before pregnancy and 6 months postpartum.

Subjects

From September 1986 to September 1988 40 women were recruited for the study. All women were healthy and had uncomplicated singleton pregnancies. The physical fitness of the subjects who entered the study was variable, ranging from women with a sedentary lifestyle to competitive sportswomen. All women were encouraged to maintain their usual physical activities during the study period and their activity pattern was verified by means of a questionnaire. The study was approved by the Erasmus University and Hospital Ethics Committee, and all women included in the study gave their informed consent.

Exercise protocol

The exercise was performed in an airconditioned room kept at 21°C and 55% humidity. Before each test a routine physical and obstetric examination was performed and the fetal heart rate was monitored with doppler ultrasound (Corometrics, Fetal monitor 111, Wallingford, Connecticut) to confirm the health of all individuals participating in the study. In addition, body weight and skinfold thickness were determined.

After 20 minutes of rest, the subject was seated on the bicycle ergometer (Mijnhardt, II FE ergometer 400 L, Bunnik, The Netherlands) and was connected to an ECG monitor (Honeywell, RM 102, Best, The Netherlands) and a gas flowmeter and oxygen analyzer (Mijnhardt, Oxycon-4, Bunnik, The Netherlands). After an additional 5 minutes of rest on the bicycle ergometer, during

which period baseline measurements were taken, the woman started exercising. Three minutes of warming up at 30 Watts were followed by a stepwise increase in exercise intensity of 10 Watts every 30 seconds until maximal aerobic power was achieved. This was followed by 5 minutes of cooling down at 10 Watts, whereafter the subject recovered for 20 minutes in semi-supine position. After 50 minutes of rest, the treadmill test was preceded by 5 minutes of standing on the treadmill (Jaeger, Laufergotest Junior, Wurzburg, Germany), which was set at a fixed slope of 12%; control measurements were taken during this time. After the subject warmed up for 3 minutes at a speed of 2.0 $km.hr^{-1}$, the speed was increased by 0.33 $km.hr^{-1}$ every 30 seconds until maximal aerobic power was achieved. After 5 minutes of cooling down at a speed of 1.0 $km.hr^{-1}$, the subject recovered for 20 minutes in semi-supine position. During the recovery periods the fetal heart rate was monitored; details of this part of the study will be presented in Chapter 3.

Maximal aerobic power was defined by the sensation of maximal effort and the presence of at least 2 of the following 3 objective criteria: 1. an increase in oxygen uptake of less than 5% in response to an increase in exercise intensity, 2. an increase in heart rate of less than 5% in response to an increase in exercise intensity, and 3. a respiratory exchange ratio of more than 1.0.

Measurements

To detect major changes in activity pattern during the study period, the subjects were asked to record their daily activities in 5-min periods for 24 hours on the same day of the week before each test. Metabolic constant values were assigned to these activities and, for each subject and each test period, the physical activity index was calculated as the 24-hours average metabolic constant; from the calculated value 1.0 was substracted for basal metabolism (123).

During every exercise test R-R intervals on the ECG recording, gas flow, and expiratory O_2 and CO_2 concentrations were continuously measured, and time and exercise intensities were recorded. All data were recorded by computer (Apple II E, Cork, Ireland). On-line 30-seconds averages were calculated of heart rate (HR), oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), minute ventilation ($\dot{V}E$), respiratory exchange ratio (R), and ventilatory equivalents for oxygen ($\dot{V}E/\dot{V}O_2$) and carbon dioxide ($\dot{V}E/\dot{V}CO_2$), and stored on diskette. Power (W) during bicycle exercise was indicated by the calibrated electronic ergometer. Power during treadmill exercise was expressed as vertical power (W) and calculated as force [body weight (kg) x acceleration of gravity ($m.s^{-2}$)] x vertical speed ($m.s^{-1}$). Work performed was calculated by taking the time integral of power, and "efficiency" of work was defined as work relative to oxygen uptake (exercise minus rest) during the period of time in which the work was performed.

Statistical analysis

From the 30-sec average values mean baseline values were calculated at 2.0-4.5

min of rest. For every test period and every variable under consideration mean values and standard errors of the means were computed. Two-way analysis of variance and the rank-sign test were used to assess differences between paired variables, and the Mann-Whitney test was applied to evaluate differences between groups. A p-value of < 0.05 was taken as the level of significance. In addition, linear regression analysis was applied to study relationships between variables.

2.3 **RESULTS**

Subjects

Of the 40 women recruited, 7 withdrew from the study: 3 women found the tests physically and/or mentally too demanding, and one subject was unable to meet the objective criteria for a maximal test. Three women could not complete the test series for various medical reasons most likely not related to the exercise: one delivered at 34 weeks, one was admitted to the hospital with threatened preterm labor, and one developed migraine treated with a beta-blocker at the time of the postpartum test. All data obtained from these 7 women were discarded; the remaining 33 women completed all tests.

All 33 women, 23 primiparae and 10 multiparae, remained healthy throughout the study period and were delivered of healthy infants. Mean (± SE) age at the time of delivery was 30.9±0.7 years, gestational age was 40.3±0.2 weeks, and birth weight was 3.43±0.08 kg. Birth weight for gestational age, corrected for parity and fetal sex, was between the 10th and 90th percentile of the reference curve in 28, below the 10th percentile in 4, and above the 90th percentile in 1 infant. Seventeen women were lactating at the time of the postpartum test. Age, length of gestation and birth weight were unrelated to physical fitness, expressed as maximal oxygen uptake per kilogram body weight at the time of the postpartum test.

Each woman underwent an initial test to become acquainted with the experimental circumstances; the data obtained in this test were discarded. All women were subsequently studied at 16.1±1.0 weeks, 25.3±0.7 weeks, and 35.0±0.6 weeks of pregnancy, and at 6.7±1.4 weeks after delivery.

Body weight and skinfold thickness determined at 16 weeks' gestation (68.0±1.7 kg, 51.2±3.5 mm) were not different from postpartum control values (67.6±1.9 kg, 50.9±3.7 mm), but increased significantly with advancing gestational age, to 71.8±1.8 and 75.3±1.8 kg, and to 54.3±3.8 and 55.3±3.9 mm at 25 and 35 weeks' gestation, respectively. Maximal oxygen uptake per kilogram of body weight determined during treadmill testing in the postpartum period was taken as an index of physical fitness and varied between 21.4 and 56.4 ml $O_2.min^{-1}.kg^{-1}$ with a mean value of 36.1±1.5 ml $O_2.min^{-1}.kg^{-1}$. Physical activity reported at 16 weeks' gestation was similar to that reported postpartum, with an index of 0.64±0.03 and 0.65±0.02, respectively. Physical activity tended to decrease during

the course of pregnancy, to an index of 0.60±0.03 and 0.58±0.03 at 25 and 35 weeks of pregnancy, respectively, but the reduction in physical activity with advancing gestation was not statistically significant.

Control values at rest

The effects of pregnancy on control values at rest are summarized in Table 2.1.

Oxygen uptake at rest, while sitting on the bicycle ergometer, was significantly elevated throughout pregnancy compared with postpartum values. It showed a linear increase ($r = 0.48$) with body weight as pregnancy advanced, to an average value at 35 weeks' gestation of 14% above the postpartum control value of 268±8 $ml.min^{-1}$. Consequently, oxygen uptake per kilogram of body weight during pregnancy was not different from the postpartum control value of 4.0±0.1 $ml.min^{-1}.kg^{-1}$.

Table 2.1. Effect of pregnancy on control values at rest.

	heart rate ($beats.min^{-1}$)	O_2 uptake ($ml.min^{-1}$)	CO_2 output ($ml.min^{-1}$)	ventilation ($L.min^{-1}$)
Bicycle (sitting)				
16 weeks	87±2$^+$	288±7$^+$	232±7*	11.4±0.3*
25 weeks	89±2*	293±7*	238±7*	11.5±0.3*
35 weeks	94±2*	306±8*	253±7*	12.3±0.3*
postpartum	83±2	268±8	211±6	9.5±0.2
Treadmill (standing)				
16 weeks	102±3*	303±9$^+$	225±7*	12.0±0.3*
25 weeks	102±3*	318±10*	238±8*	12.2±0.3*
35 weeks	104±2*	341±12*	262±10*	13.3±0.4*
postpartum	97±3	286±10	206±8	9.6±0.3

Values are means±SE; $^+p < 0.05$ and $*p < 0.01$ compared with postpartum control values, n=33.

Heart rate at rest was consistently elevated throughout pregnancy and increased with oxygen uptake to an average value at 35 weeks' gestation that was 13% higher than the postpartum control value of 83±2 $beats.min^{-1}$.

Carbon dioxide output at rest was also found to be elevated during pregnancy. With advancing gestation it increased progressively to values of 10,13, and 20%, at 16, 25, and 35 weeks' gestation, respectively, above the postpartum control value of 211±6 $ml.min^{-1}$. Because during pregnancy the increase in CO_2 output was slightly more pronounced than the increase in O_2 uptake, the respiratory exchange ratio at rest was also slightly elevated above the postpartum control value of 0.79± 0.01, to a maximum value of 0.82±0.01 at 35 weeks' gestation.

Ventilation at rest was elevated by 20, 21, and 29%, at 16, 25, and 35 weeks of pregnancy, respectively, compared with the postpartum control value of

9.5±0.1 L.min^{-1}. The frequency of 15.8±0.4 ventilations.min^{-1} was unaffected by pregnancy and, for that reason, the changes in minute ventilation during pregnancy must be attributed to an increase in tidal volume (0.74±0.02, 0.75±0.02, 0.79±0.02, and 0.61±0.02 L.min^{-1} at 16, 25, and 35 weeks' gestation, and postpartum, respectively). Because ventilation showed a more marked increase than did metabolism, the ventilatory equivalents for O_2 and CO_2 at rest rose during pregnancy, to values that were 13 and 18% higher than the respective postpartum control values of 35.9±0.4 and 45.6±0.7.

Values of oxygen uptake and heart rate obtained from the subjects standing at rest on the treadmill, after 55 minutes of recovery from bicycle exercise, were increased by an average of 8% and 14%, respectively, compared with resting values before bicycle exercise. In contrast, carbon dioxide output was not different and, consequently, the respiratory exchange ratio was on average 7% lower while the subject stood at rest on the treadmill. During pregnancy the ventilation at rest on the treadmill was 8% higher than that before bicycle exercise. The increased ventilation appeared to be due to an increase in frequency from 15.7±0.4 to 16.8±0.4 ventilations.min^{-1}, without a significant change in tidal volume. In contrast, in the postpartum period ventilation appeared to be unaffected by the change in body position and the previous exercise.

Maximal aerobic exercise

Heart rate and oxygen uptake showed a linear increase with increasing exercise intensity. At near-maximal levels of aerobic exercise both variables formed a plateau, with values of heart rate and oxygen uptake remaining within 95% of the maximum for 98±6 and 39±7 sec, respectively, at the time of the postpartum bicycle test. Pregnancy did not significantly affect the length of these plateaus.

The effects of pregnancy on maximal responses during exercise are demonstrated in Table 2.2 and Figure 2.1; the differences (exercise minus rest) are given in Table 2.3.

Bicycle exercise. Power during bicycle exercise increased in a linear fashion with exercise time after the three minutes of warming up. Mean exercise time and maximal power at 16 and 25 weeks' gestation were not different from the postpartum control values of 11.5±0.3 min and 199±7 W, respectively. At 35 weeks' gestation exercise time was significantly reduced by 0.4±0.1 min and maximal power by 8±3 W, or 4%, in comparison to postpartum values.

Maximal heart rate during bicycle exercise was on average 4±1 beats.min^{-1} (2%) lower throughout pregnancy compared with the postpartum control value of 178±2 beats.min^{-1}.

In contrast, maximal oxygen uptake was not significantly different between test periods. As a result of the increase in oxygen uptake at rest, the amount of oxygen available for exercise (exercise minus rest) decreased by an average

Table 2.2. Effect of pregnancy on maximal responses during exercise.

	power (W)	heart rate (beats.min^{-1})	O_2 uptake (L.min^{-1})	CO_2 output (L.min^{-1})	ventilation (L.min^{-1})
Bicycle					
16 weeks	202±7	174±2*	2.20±0.08	2.56±0.09*	95.6±3.2*
25 weeks	196±7	174±2*	2.16±0.08	2.51±0.08*	94.6±2.9*
35 weeks	191±7*	174±2*	2.15±0.08	2.46±0.09*	96.1±3.5*
postpartum	199±7	178±2	2.19±0.08	2.70±0.09	89.5±3.0
Treadmill					
16 weeks	165±5	180±2*	2.45±0.08	2.72±0.09	98.8±2.6*
25 weeks	164±5	178±2*	2.38±0.09	2.66±0.09$^+$	99.6±3.3*
35 weeks	162±5	178±2*	2.33±0.09	2.55±0.09*	98.1±3.0*
postpartum	163±5	183±2	2.39±0.08	2.79±0.08	91.7±2.6

Values are means±SE; $^+p < 0.05$ and $*p < 0.01$ compared with postpartum control values, n=33.

Table 2.3. Effect of pregnancy on maximal changes from rest during exercise.

	heart rate (beats.min^{-1})	O_2 uptake (L.min^{-1})	CO_2 output (L.min^{-1})	ventilation (L.min^{-1})
Bicycle				
16 weeks	88±2*	1.91±0.08	2.33±0.09$^+$	84.2±3.1$^+$
25 weeks	85±2*	1.87±0.08	2.27±0.08*	83.2±2.9$^+$
35 weeks	79±2*	1.84±0.08	2.21±0.09*	83.8±3.5
postpartum	95±2	1.92±0.07	2.49±0.08	80.0±3.0
Treadmill				
16 weeks	77±2*	2.14±0.08	2.50±0.09	86.8±2.5$^+$
25 weeks	76±2*	2.06±0.09	2.42±0.09*	87.4±3.2*
35 weeks	74±2*	1.99±0.08*	2.29±0.08*	84.8±2.9
postpartum	86±2	2.10±0.07	2.59±0.08	82.1±2.5

Values are means±SE; $^+p < 0.05$ and $*p < 0.01$ compared with postpartum control values, n=33.

of 4% during the course of pregnancy, but pregnancy and postpartum values were not statistically different. With maximal reductions of 4% in both maximal power and oxygen available for exercise at 35 weeks' gestation, overall "efficiency" for bicycle exercise during pregnancy was not significantly different from the postpartum value of 6.3±0.1 kJ.LO_2^{-1}.

Carbon dioxide output at maximal exercise was found to be significantly lower during pregnancy than postpartum, despite increased values at rest. The exercise-induced increase in CO_2 output was lower by 6, 9, and 11% at 16, 25, and 35 weeks', respectively, compared with the postpartum value of

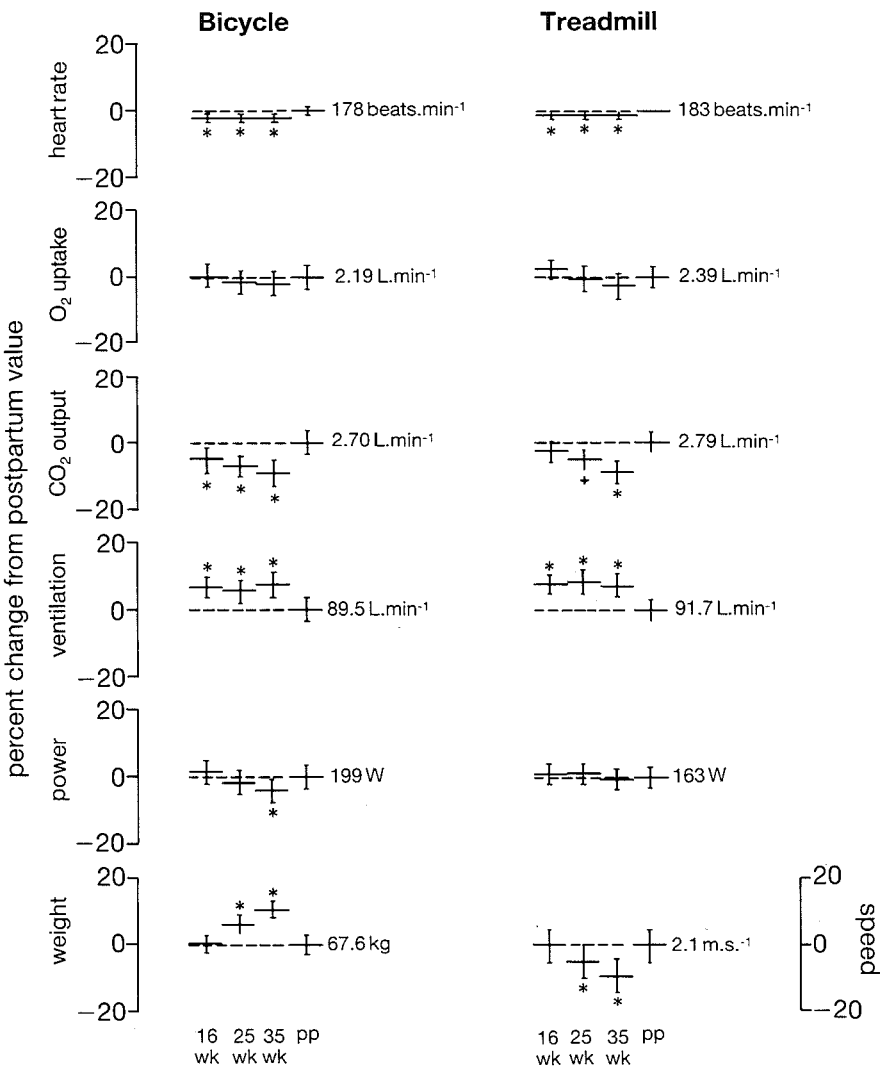

Fig. 2.1 Percent changes (mean ± SE) from postpartum values (pp) of weight and maximal heart rate, O_2 uptake, CO_2 output, ventilation, power, and speed during bicycle and treadmill exercise at 16, 25, and 35 weeks of pregnancy (16 wk, 25 wk, 35 wk). Significant changes indicated by + ($p < 0.05$) and * ($p < 0.01$); n=33.

2.49±0.08 L.min^{-1}. Without a similar fall in oxygen uptake, the calculated respiratory exchange ratios at maximal aerobic exercise showed significant reductions of about 7% compared with the postpartum control value of 1.25±0.02.

During bicycle exercise in pregnancy, ventilation increased to an average maximal value of 7% above the postpartum control value of 89.5±3.0 L.min^{-1}. Maximal frequency averaged 45.4±1.3 ventilations.min^{-1} with no significant differences among the 4 test periods, whereas maximal tidal volume was about 6% higher during pregnancy than in the postpartum period (2.29±0.07 and 2.17±0.07 L.min^{-1}, respectively). Because during gestation maximal ventilation was increased and maximal O_2 uptake was virtually unaffected, the ventilatory equivalent for oxygen was significantly higher during pregnancy, with average values of 7% above the postpartum control value of 42.0±1.2. Because CO_2 output at maximal aerobic exercise was higher than O_2 uptake, the ventilatory equivalent for CO_2 at maximal aerobic exercise was markedly lower (35.4±0.5 and 42.0±1.2 postpartum, respectively) than that for O_2.The difference in the ventilatory equivalent for CO_2 between pregnancy and postpartum test periods that existed at rest was maintained during maximal aerobic exercise.

Figure 2.2 shows maximal responses of heart rate, oxygen uptake, carbon dioxide output, and ventilation at 35 weeks' gestation and 7 weeks postpartum as a function of maximal power for bicycle exercise. The lines that represent the linear relationships between these variables and power are shifted during pregnancy virtually parallel to those obtained postpartum. This demonstrates that the pregnancy changes were independent of the level of maximal power.

Treadmill exercise. After subjects warmed up, treadmill speed was increased linearly with time. Because in treadmill exercise the production of power was calculated as body weight times speed times a constant, it increased as a function of weight and time, whereas in bicycle exercise it varied only as a function of time. Consequently, the heavier the individual, the more rapidly progressive the treadmill protocol was in terms of exercise intensity. Nonetheless, maximal power was unaffected by pregnancy because exercise time, or maximal speed, was inversely related to body weight. Average maximal speed measured at 16 weeks' gestation was equal to that observed postpartum (2.1±0.1 m.s^{-1}) but decreased to 2.0±0.1 and 1.9±0.1 m.s^{-1} at 25 and 35 weeks' gestation, respectively. The time required to reach maximal aerobic power was 11.3±0.4, 10.6± 0.4, 10.0±0.3, and 11.3±0.4 min at 16, 25, and 35 weeks' gestation and postpartum, respectively.

Values of maximal heart rate, oxygen uptake, carbon dioxide output, and ventilation obtained during treadmill exercise were consistently higher than those during bicycle exercise.

Maximal heart rate during pregnancy was approximately 4 beats.min^{-1} lower than that observed at the postpartum test, and during treadmill exercise maximal oxygen uptake in pregnancy was not different from the postpartum control value of 2.39±0.08 L.min^{-1}. The amount of oxygen available for maximal treadmill exercise (maximum minus rest) was not different from the postpartum control value of 2.10±0.07 L.min^{-1} at 16 and 25 weeks' gestation, but was 5%

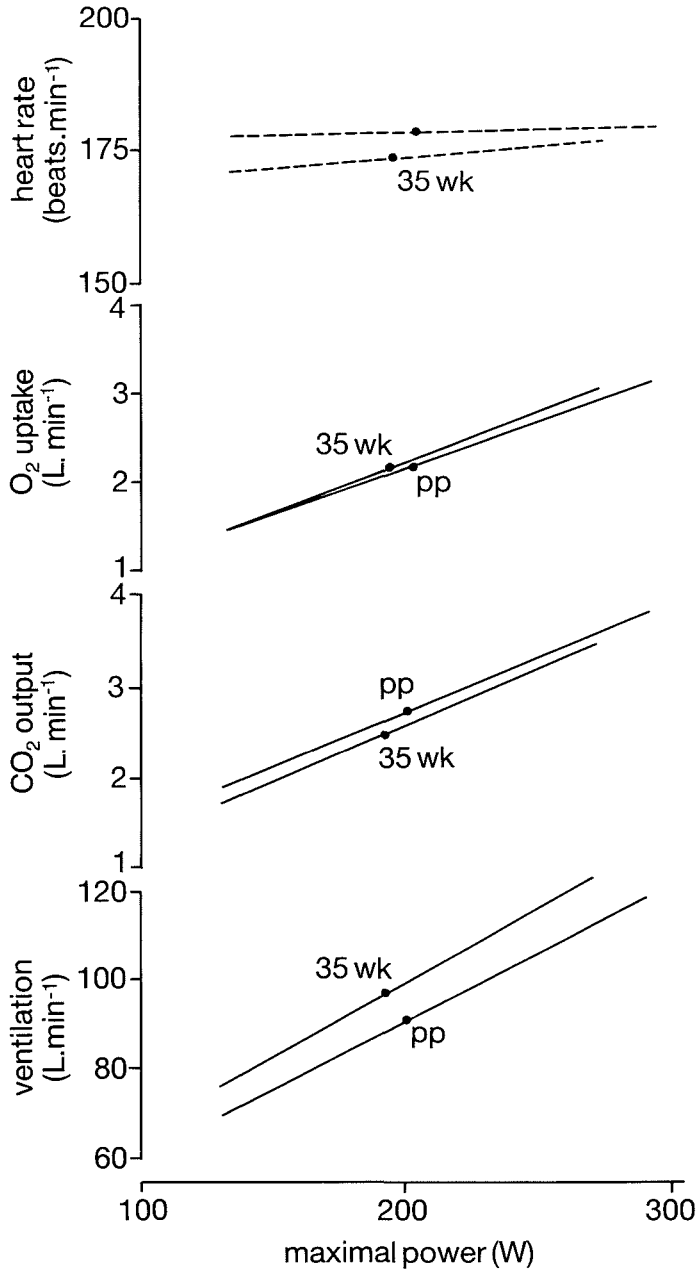

Fig. 2.2 Maximal values of heart rate, O_2 uptake, CO_2 output, and ventilation, related to maximal power during bicycle exercise at 35 weeks' gestation (35 wk) and 7 weeks postpartum (pp). Solid lines represent significantly related variables; dashed lines variables that are not significantly related, points indicate means values; n=33.

lower than control at 35 weeks' gestation, as a result of increased oxygen uptake at rest. Oxygen uptake was higher and calculated work was lower in treadmill exercise than in bicycle exercise. Therefore, the calculated "efficiency" was on average 25% lower during treadmill exercise than during bicycle exercise (4.7±0.1 and 6.3±0.1 $kJ.LO_2^{-1}$ postpartum, respectively). Because the amount of oxygen available for treadmill exercise at 35 weeks' gestation was 5% lower than that in the postpartum period whereas power was unaffected, "efficiency" was calculated to increase significantly by approximately 6% in late gestation.

Maximal carbon dioxide output was 5% higher and oxygen uptake 10% higher during treadmill exercise than during bicycle exercise. As a consequence, the respiratory exchange ratio was on average 4% lower during treadmill exercise than during bicycle exercise, when it averaged 1.16±0.01 during pregnancy and 1.25±0.02 postpartum. Ventilation increased to higher absolute values during treadmill exercise than during bicycle exercise. The increase was less pronounced than the increase in O_2 uptake but proportional to the change in CO_2 output. As a consequence, the ventilatory equivalent for O_2 tended to be slightly lower during treadmill exercise than during bicycle exercise, whereas the ventilatory equivalent for CO_2 was similar during both types of exercise.

Nonpregnant control values

Nonpregnant control values were obtained in 4 highly motivated women, studied longitudinally from 3 months before gestation to 6 months after delivery. The results of the three non-pregnant test periods are presented in Table 2.4. In these 4 women heart rate at rest was below the average, and maximal power and oxygen uptake were above the average of the 33 women, which demonstrates

Table 2.4. Comparison of nonpregnant values at rest and maximal bicycle exercise.

	pre-pregnancy	7 weeks postpartum	6 months postpartum
Rest (sitting)			
weight (kg)	67.2±6.5	70.8±7.5	68.1±7.4
heart rate ($beats.min^{-1}$)	74±4	75±5	71±6
O_2 uptake ($ml.min^{-1}$)	283±25	283±23	270±11
CO_2 output ($ml.min^{-1}$)	228±17	230±16	218±10
ventilation ($L.min^{-1}$)	10.1±1.1	10.7±0.7	9.7±0.5
Maximum (bicycle)			
power (W)	223±19	213±18	220±17
heart rate ($beats.min^{-1}$)	167±5	171±5	172±6
O_2 consumption ($L.min^{-1}$)	2.37±0.25	2.30±0.23	2.34±0.22
CO_2 production ($L.min^{-1}$)	2.70±0.31	2.77±0.30	2.71±0.26
ventilation ($L.min^{-1}$)	87.5±13.5	89.6±14.9	92.3±10.2

Values are means±SE; n = 4.

their relatively good physical fitness. For the physiological variables under consideration the average values at rest and maximal bicycle exercise at 7 weeks after delivery in these women were not different from prepregnancy values or from values obtained 6 months postpartum. This was also the case for treadmill exercise (not shown in Table 2.4). The limited number of observations does not allow statistical analysis of these differences.

2.4 DISCUSSION

The study shows progressive increases with advancing gestation in heart rate, O_2 uptake, CO_2 output, and ventilation in pregnant women at rest. This is in agreement with reports in the literature (69) and reflects the physiological adaptations of the mother to meet the needs of the growing conceptus.

Resting values of heart rate and oxygen uptake before treadmill exercise were higher than those obtained before bicycle exercise in both pregnant and nonpregnant women. Because in the design of the study the bicycle test always preceded the treadmill test, it cannot be determined with certainty whether the higher values at rest resulted from increased effort to maintain the standing position (11) or from incomplete recovery from bicycle exercise. However, because the exercise test was rapidly progressive to limit the development of lactic acid oxygen debt, and because oxygen debt is rapidly resolved at a half time of approximately 15 minutes (87), the values obtained after 55 minutes of recovery from bicycle exercise may be expected to approach true resting values. Absolute values of maximal heart rate and oxygen uptake are known not to be markedly affected by previous exercise (11), and errors in resting values have a relatively small effect on the changes (exercise minus rest) because of the magnitude of the values at maximal aerobic exercise. Therefore, even if the resting values before treadmill exercise were slightly increased above the true resting-state level, this still should not have markedly affected the maximal responses as presented in Tables 2.2 and 2.3, and Figure 2.1.

In this study it was found that the output of carbon dioxide at rest increased progressively during pregnancy, in absolute terms as well as relative to oxygen uptake. This resulted in an increase in the respiratory exchange ratio at rest, as observed previously (77). In steady-state conditions this indicates an increased contribution of carbohydrates or amino acids to aerobic metabolism which, in pregnancy, may reflect the contribution to "basal" metabolism of the fetal-placental unit. Both the fetus and the placenta utilize predominantly carbohydrates as fuel for their metabolism (70).

The results of this study confirm earlier observations (69,92) that ventilation is increased during pregnancy as a result of an increase in tidal volume without a change in frequency, and that ventilation increases more than does oxygen uptake. This leads to a reduction in maternal CO_2 tension which facilitates the transfer of CO_2 across the placenta from the fetus to the mother. The

increase in ventilatory equivalent in pregnancy could be a hormonal effect, in particular due to the high circulating levels of progesterone (69,92).

In nonpregnant subjects, the values of heart rate, O_2 uptake, CO_2 output, and ventilation observed during maximal treadmill exercise are higher than those obtained during bicycle exercise (11). The present study shows that this is also the case in pregnant and postpartum women. Maximal heart rate is affected by age and by the type of exercise, but it is otherwise remarkably constant within individuals (11). In the present study maximal heart rate was 4 beats.min^{-1} lower throughout pregnancy during bicycle and treadmill exercise, and Sady et al. (114) reported that maximal heart rate during bicycle exercise was 2 beats.min^{-1} lower during pregnancy. Although the reduction of 2% in maximal heart rate during pregnancy was statistically significant, this change seems to be too small to be of physiological importance.

Maximal oxygen uptake was not significantly affected by pregnancy, although there was a tendency toward lower values with advancing gestation. This is in agreement with observations by Sady et al. (114), who reported similar values of maximal oxygen uptake during bicycle exercise at 26 weeks' gestation and postpartum. In contrast, 12% lower values of maximal oxygen uptake were observed during treadmill exercise in a cross-sectional study in which a group of pregnant women at 29 weeks' gestation was compared with a group of nonpregnant women (7). The same study reported a 34% reduction in maximal oxygen uptake expressed per kilogram of body weight in pregnant women compared with nonpregnant control subjects (7). In addition to differences between the groups of women that may have resulted from the cross-sectional design of the study, the standardization of oxygen uptake for body weight is misleading with respect to the changes in oxygen uptake during exercise in pregnancy. Weight gain during pregnancy results from a gradual increase in fetal-placental mass, water and fat, with no appreciable change in muscle mass (84). Consequently, in pregnant women oxygen uptake expressed per kilogram of body weight may adequately describe the changes in oxygen uptake at rest, but it will give a false impression when applied to physical exercise (84).

Maximal oxygen uptake is largely a function of muscle mass and physical fitness (11). In the present study the pregnant volunteers were instructed to maintain their usual pattern of physical activity to avoid an effect of training or deconditioning on the responses during the study period. The questionnaire data indeed suggest that the women complied with the instructions. Because pregnancy does not affect muscle mass, the pregnancy responses were not only unaffected by the level of maximal bicycle power as shown in Figure 2.2, but also independent of the level of physical fitness.

The maximal amount of oxygen available for exercise equals maximal oxygen uptake minus oxygen uptake at rest. With advancing gestation oxygen uptake at rest increases, when "basal" oxygen consumption, including that of the fetus and placenta, increases progressively. Although the amount of oxygen available for exercise tended to fall with advancing gestation, the decrease reached

statistical significance only during treadmill exercise at 35 weeks' gestation when oxygen uptake at rest attained its highest level.

In a recent study, it was found that a similar weightbearing task required more oxygen during pregnancy than it did 8 weeks postpartum when a belt was used to correct for the postpartum reduction in body weight (26). The authors concluded that about 50% of the marginally significant difference in total oxygen uptake could be accounted for by weight increase per se, 25% by increased metabolism at rest, and 25% by intrinsic pregnancy changes. When net oxygen uptake (exercise minus rest) increases while speed, weight, and consequently power are kept constant, it implies a reduction in "efficiency". This is in contrast to another recent study in which it was concluded that pregnancy markedly increases exercise efficiency (35). The conclusion was based on the fact that a certain amount of calculated vertical work required less oxygen during pregnancy than it did in the nonpregnant state. The observation in the present study that power was unaffected by pregnancy, whereas the amount of oxygen available for exercise was reduced during treadmill exercise at 35 weeks' gestation, could also suggest a higher "efficiency". However, such a suggestion must be refuted. Margaria et al (87) observed that the net energy cost per kilometer increases progressively at higher speeds of walking or running uphill. This may explain the observation of a 6% higher calculated "efficiency" in maximal treadmill exercise at 35 weeks' gestation, when maximal speed was indeed less than that observed at the time of the postpartum test. It seems likely that also in the study cited above (35) a reduction in speed was responsible for the changes during gestation, rather than an increase in exercise efficiency per se. In addition, an increase in oxygen debt could add to the impression of increased "efficiency" during pregnancy.

The respiratory exchange ratio during exercise was found to be significantly lower in pregnancy than it was in the postpartum period. Considering that virtually no difference in power was found, the reduction in respiratory exchange ratio during pregnancy may have resulted from such factors as substrate utilization, pH, or oxygen debt. The data do not allow assessment of the relative importance of these mechanisms.

The study shows that the relative hyperventilation of pregnancy persists at maximal aerobic power. Ventilation is governed by O_2 uptake, CO_2 output, and by the pH of the blood (130). In the present study, CO_2 output and ventilation were significantly correlated with O_2 uptake and with each other. The parallel shift observed during pregnancy of the curves that represent CO_2 output and ventilation relative to O_2 uptake suggests that the regulatory mechanisms are unaffected by pregnancy but that the setpoints are changed. It seems likely that this is mediated through the same mechanism during exercise as it is at rest, i.e. progesterone.

The design of the present study may be criticized on two points. First, the bicycle and treadmill tests were not performed in a random order, which limits the value of comparisons between the two tests. The treadmill test was considered

to be so strenuous, especially late in gestation, that volunteers might fail to do a subsequent bicycle test. It was felt that the primary aim of the study, i.e. to assess the effects of pregnancy, would be served best by executing identical tests in all test periods and by performing the less demanding bicycle test first. Second, control measurements were taken 7 weeks postpartum and may not represent the true nonpregnant state. However, values for maximal heart rate and oxygen uptake in 4 volunteers recruited before pregnancy were similar when determined before pregnancy, during pregnancy, 7 weeks postpartum, and 6 months postpartum. Therefore, it seems likely that the postpartum values represent the true nonpregnant condition.

It is concluded that pregnancy does not markedly affect either maximal heart rate or maximal oxygen uptake. The increased oxygen uptake at rest, which results largely from increased "basal" metabolism - including that of the fetus and the placenta -, tends to reduce the amount of oxygen available for exercise at very high levels of (treadmill) exercise in late gestation. The relationship between power and oxygen uptake is not affected by pregnancy.

Chapter 3

MATERNAL AND FETAL CARDIOVASCULAR RESPONSES TO STRENUOUS BICYCLE EXERCISE

3.1 INTRODUCTION

With ever increasing numbers of pregnant women wanting to participate in sport activities the question whether maternal exercise is safe for mother and fetus becomes more and more important. With regard to the mother, the cardiovascular adjustments to strenuous physical activities could be dangerous because of the added burden to an already hyperdynamic maternal circulation. On the other hand, the increased compliance of the dilated vascular bed in pregnancy (129) could have a protective effect on the circulation and could depress the maternal blood pressure response to exercise.

Physical exercise of the mother presents a potential threat to fetal health because uterine blood flow is known to decrease progressively with exercise intensity (84). Results of early studies in healthy pregnant women suggested that even mild to moderate exercise may occasionally be associated with fetal bradycardia (5,75), but this finding was later dismissed as representing an artefact (102). Animal studies have demonstrated that several compensatory mechanisms act together to preserve fetal oxygen consumption even during exhaustive exercise (84). These observations provide the justification for a study of maternal and fetal responses to strenuous exercise in healthy pregnant women.

The aim of the present study in healthy pregnant women with an uncomplicated pregnancy was to assess physiological responses to strenuous bicycle exercise relevant to the safety of the mother and her fetus: maternal electrocardiogram (ECG), blood pressure, uterine contractility, and fetal heart rate.

3.2 MATERIAL AND METHODS

The study was performed in thirty-three women at 16, 25, and 35 weeks' pregnancy, and 7 weeks after delivery. The design and the execution of the experiments were reported in detail in Chapter 2, and will be summarized only briefly here.

After 20 minutes of rest in semi-supine position, the subject was asked to sit on a bicycle ergometer. She was connected to a gas flow meter for the study of maximal oxygen uptake, reported in Chapter 2. The volunteer was also connected to an ECG monitor (Honeywell, RM 102, Best, The Netherlands) and a bipolar electrocardiogram, lead CM_5, from manubrium to the left precordial position (V5), was continuously recorded (Cardiostat, Siemens,

Germany). Blood pressure was measured at 3-minutes' intervals, with a standard sphygmomanometer (Erka-Sphygmomanometer, Germany) and auscultation using Korotkoff sounds I and V to indicate systolic and diastolic blood pressures, respectively. After 5 minutes of baseline measurements at rest on the ergometer, the subject started to exercise. Three minutes of warming up at 30 Watts were followed by stepwise increments in exercise intensity of 10 Watts every 30 seconds until maximal oxygen uptake ($\dot{V}O_2max$) was reached. This was followed by 5 minutes of cooling down at 10 Watts. Fetal heart rate was recorded by means of doppler-ultrasound and uterine contractility by external tocodynamometry (Corometrics, Fetal Monitor 111, Wallingford, Connecticut). The cardiotocogram was recorded in semi-supine position during the 20 minutes of rest before the subject was seated on the bicycle ergometer and during 20 minutes of recovery from exercise, in the second and third trimester of pregnancy. The cardiotocogram could not be obtained reliably during the exercise test itself.

The electrocardiograms were evaluated according to previously established criteria (53). Mean blood pressures were calculated as 1/3 x (systolic pressure + 2 x diastolic pressure). The cardiotocograms were evaluated in a blinded fashion with the use of the Fischer score (59) and the frequency of contractions was determined. In addition, the average basal fetal heart rate was calculated during the last 5 minutes of rest and the first 5 minutes of recovery in semi-supine position.

For each test period and each variable under consideration mean values and standard errors of the mean were computed. The Student t-test was used to assess differences between paired variables. A p-value of < 0.05 was taken as the level of significance.

3.3 **RESULTS**

Some general characteristics of the 33 women and their pregnancies were presented in Chapter 2.3.

All subjects were studied at 16.1±1.0 weeks, 25.3±0.7 weeks, and 35.0±0.6 weeks of pregnancy, and at 6.7±1.4 weeks after delivery. Maternal heart rate at rest increased significantly with advancing gestational age from 87±2 beats.min^{-1} at 16 weeks' to 89±2 beats.min^{-1} at 25 weeks' and 94±2 beats.min^{-1} at 35 weeks' gestation, as compared to 83±2 beats.min^{-1} postpartum. Heart rate showed a linear increase with exercise intensity to a maximum of 174±2 beats.min^{-1} throughout pregnancy and 178±2 beats.min^{-1} postpartum. Analysis of the resting electrocardiograms for abnormal changes in conduction, repolarization, and rhythm showed no anomalies in 30 women; 2 demonstrated sinus arrhythmia and 1 had an ectopic atrial rhythm. During exercise, 28 women had a normal electrocardiogram throughout pregnancy and postpartum; 4 subjects showed ST-segment depression of $\geqslant 0.1$ mV, in 1 subject accompanied

by an inverted T-wave. Sinus arrhythmia disappeared during exercise in the two women who showed this abnormality at rest, and the ectopic atrial rhythm in one subject persisted. The ECG abnormalities during exercise in these women occurred consistently in all pregnancy and postpartum test periods. None of the 33 women had other signs or symptoms suggestive of cardiac ischemia.

Mean values of systolic, diastolic, and mean arterial pressures at rest and at approximately 75% $\dot{V}O_2$max are shown in Table 3.1 and Figure 3.2. Systolic blood pressures at rest appeared to be unaffected by pregnancy, whereas diastolic and mean pressures were slightly lower during the first and second trimester of pregnancy compared with values obtained in the third trimester and postpartum. Systolic and mean arterial pressures showed a linear increase with exercise intensity (Figure 3.1). At approximately 75% $\dot{V}O_2$max, systolic and mean arterial pressures were significantly increased by an average of 36 and 17%, respectively, whereas diastolic pressures increased marginally by an average of 2% (Table 3.1). Mean values of exercise intensity and systolic blood pressure were similar and values of diastolic pressure were slightly lower in the first and second trimester than in the postpartum period. During the third trimester the average exercise intensity at the time of the measurement was 5% higher and the systolic blood pressure during exercise was 4% higher than in the postpartum period, while the diastolic pressure was similar. Except for a marginal difference at 16 weeks' gestation, calculated mean blood pressures during exercise in pregnancy were not different from the postpartum values.

Mean fetal heart rate during the first 5 minutes after exercise showed a small but significant increase relative to the resting control value observed in the second as well as in the third trimester; in the second trimester it rose

Table 3.1. Effect of pregnancy on blood pressure at rest and during strenuous bicycle exercise.

	Blood pressures (mm Hg)			Exercise intensity
	systolic	mean	diastolic	(% $\dot{V}O_2$max)
At rest				
16 weeks	110.0±1.8	85.4±1.3*	73.0±1.2*	—
25 weeks	113.0±1.7	87.5±1.1*	74.7±1.0*	—
35 weeks	114.8±1.9	90.3±1.3	78.0±1.3	—
postpartum	112.9±1.6	90.6±1.2	79.4±1.1	—
Exercise				
16 weeks	150.3±2.7	100.8±1.4$^+$	76.1±1.1*	74.0±1.9
25 weeks	153.9±3.0	102.9±1.5	77.4±1.1$^+$	74.5±1.9
35 weeks	158.0±3.0*	105.6±1.5	79.4±1.2	76.8±2.0
postpartum	151.5±2.7	103.5±1.3	79.5±1.0	73.1±2.1

Values are means±SE; $^+p < 0.05$ and $*p < 0.01$ compared with postpartum control values, n=33. Exercise values are significantly increased above resting values ($p < 0.01$) for all variables except for diastolic blood pressure.

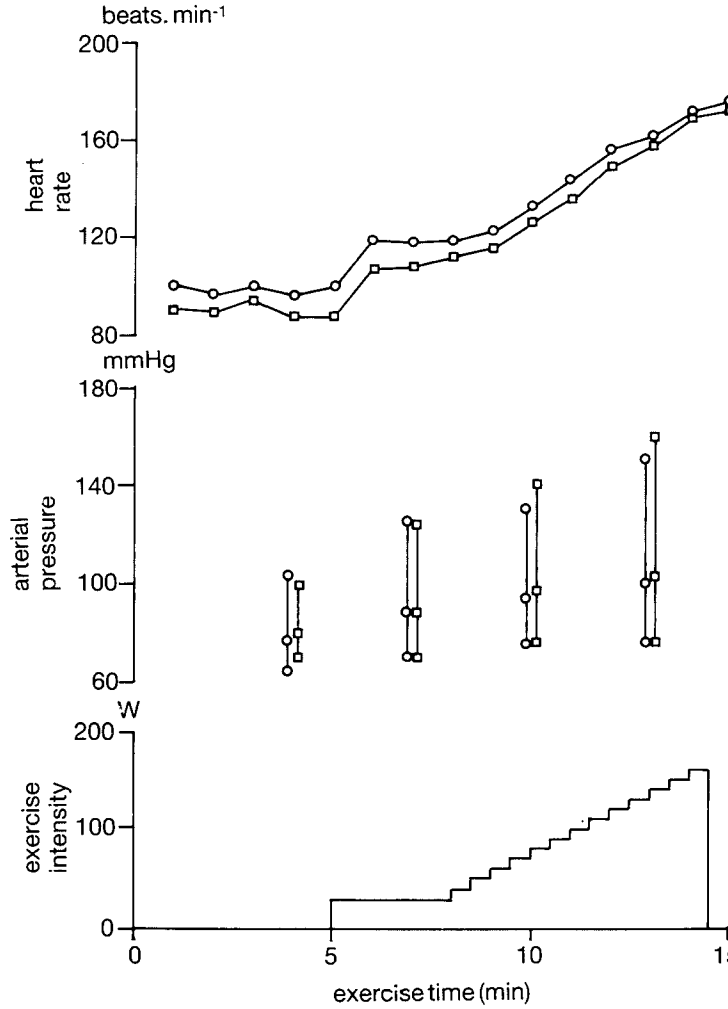

Figure 3.1. The rise in heart rate and systolic and mean blood pressures at increasing levels of exercise intensity, and the absence of change in diastolic blood pressure.
○ first trimester, □ post partum.

from 143.9±0.9 beats.min^{-1} to 148.7±1.5 beats.min^{-1}, and in the third trimester from 140.7± 1.4 beats.min^{-1} to 144.2±1.8 beats.min^{-1}. The Fischer score could not be established in 10 of the 33 subjects at 25 weeks' gestation because of poor quality of the tracings, whereas all tracings but one were satisfactory at 35 weeks' gestation. Average scores after exercise were not significantly different from those obtained at rest, both at 25 weeks' gestation (9.7± 0.2 and 9.9±0.1, respectively), and at 35 weeks of pregnancy (9.5±0.2 and 9.6±0.2, respectively).

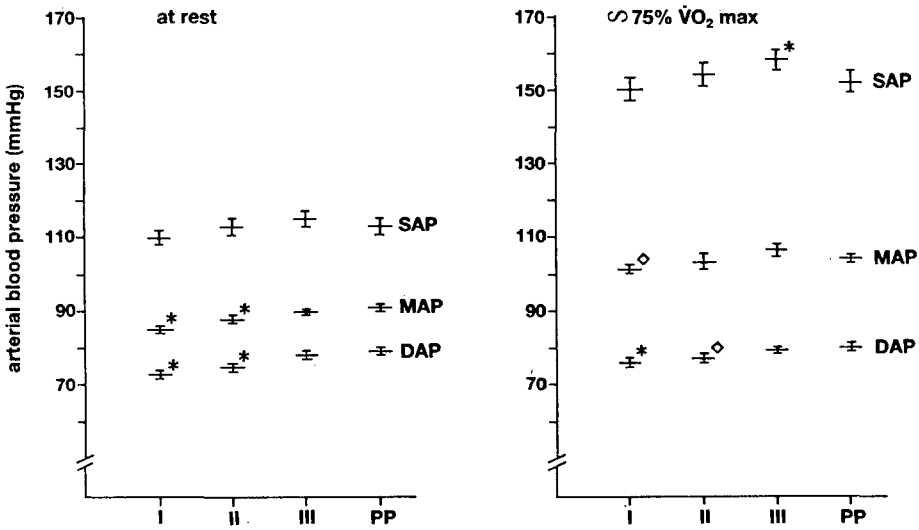

Figure 3.2. Arterial blood pressures at rest and at approximately 75% $\dot{V}O_2$max during the first (I), second (II), and third (III) trimester of pregnancy, and postpartum (pp). Systolic (SAP), mean (MAP) and diastolic (DAP) blood pressures are presented as mean values ± SE; ◇ $p < 0.05$ and * $p < 0.01$ compared with postpartum values (n=33).

At 25 weeks of pregnancy 22 of the remaining 23 fetuses had an optimal score of 8 to 10 points both at rest and following exercise. In one case the score changed from optimal (8 points) at rest to suboptimal (7 points) following exercise. At 35 weeks', 30 fetuses were scored as optimal both before and after exercise, one changed from optimal (8 points) to suboptimal (7 points) and one changed from suboptimal (7 points) to optimal (10 points).

Uterine contractility was recorded reliably from all subjects in both trimesters. At 25 weeks' gestation 32 of the 33 women showed no uterine contractions before and after exercise; in one woman uterine contractility was not present at rest but was recorded after exercise. At 35 weeks' gestation 27 women had no uterine contractions either before or after the bicycle exercise; 3 women showed some uterine contractility both before and after exercise; and 3 women showed a few irregular contractions only after exercise, which subsided spontaneously. None of the women noticed the recorded contractions or progressed into labor.

3.4 DISCUSSION

ST-segment depression was observed in 4 of the 33 (12%) studied pregnant women; similar (60) to much higher figures of up to 75% (45) have been reported from other studies in healthy pregnant women. The cause of these repolariza-

tion abnormalities remains unknown; most women with ST-depression during exercise testing have angiographically normal coronary arteries (132). It has been suggested that the ECG-changes could be due to altered sympathetic regulation (132) and one might speculate that ECG-abnormalities during exercise may occur more frequently in pregnant women (100) because pregnancy may affect sympathetic regulation (12). The findings in the present study do not suggest that pregnancy markedly increases the incidence of repolarization abnormalities or arrhythmias in exercising women, but this study does not have the power to rule out a possible effect of pregnancy. However, the data seem to support the contention that exercise electrocardiography in healthy pregnant or nonpregnant women is of limited value for the detection of ischemia (41).

In the first and second trimester of pregnancy lower diastolic pressures at rest were found compared with those observed in the third trimester and postpartum, but there were no significant differences in systolic blood pressure. This is in agreement with the literature and is thought to reflect a reduction in systemic vascular resistance (129). Systolic arterial pressure increases with exercise intensity, whereas diastolic pressure increases only slightly (11). Some authors reported a higher systolic pressure response to exercise in pregnant than in nonpregnant women (54), whereas others observed no difference (44,114). The results of the present study show that absolute values of diastolic and mean arterial pressure during exercise were slightly lower during the first and second trimester of pregnancy, which may reflect the lower resting values observed during these periods. Systolic blood pressure during exercise differed from that in the postpartum period only in the third trimester of pregnancy when it showed a statistically significant increase of 4%, or 6 mm Hg. This may well reflect the cumulative effect of the 2% higher systolic pressure at rest and the 5% higher exercise intensity during the third trimester in this study, rather than a physiologically important difference in response. The observation that the blood pressure response to exercise is virtually unaffected by pregnancy despite the hyperdynamic circulation indicates that the pressure response is governed by local demand.

The fetal heart rate response to moderately strenuous maternal exercise has been investigated repeatedly since it was proposed as a clinical test for uteroplacental insufficiency (67). The present study shows the consistent occurrance of a slightly elevated baseline fetal heart rate after the maximal bicycle test. This probably reflects the increase in body temperature rather than fetal distress and confirms similar observations after less strenuous exercise (32,39). Although abnormal heart rate patterns, including bradycardia, have been reported during exercise (5,75), other studies have adduced evidence that these abnormal patterns are artefacts caused by rhythmic maternal movements during exercise (102). In this study it appeared to be impossible to record fetal heart rate reliably during the bicycle test, but the fetal heart rate pattern was found to be unchanged after the exercise. With the use of invasive techniques

it has been demonstrated that even exercise at the point of exhaustion has little effect on fetal heart rate in experimental animals, and that fetal blood gas values remain within normal limits (83).

Uterine contractility after exercise occurred in a few women. This is in agreement with observations by others who reported either occasional slight increases (4) or no change (124) in uterine contractility in response to physical activity, without progression into labor.

In conclusion, the present study has provided no evidence that pregnancy markedly modulates the maternal electrocardiogram or blood pressure response to strenuous exercise, or that it affects the fetal heart rate pattern. The data support the view that even strenuous exercise during pregnancy is not harmful to the healthy mother and fetus.

Chapter 4

ERRORS IN PREDICTING MAXIMAL OXYGEN UPTAKE IN PREGNANT WOMEN

4.1 INTRODUCTION

Maximal oxygen uptake ($\dot{V}O_2max$) is probably the best indicator of the ability of an individual to perform endurance exercise. It can be measured reliably in a maximal exercise test, but exercise testing is often limited to submaximal intensities. In pregnant women, the study of exercise responses has been limited largely to submaximal exercise intensities because of fetal health concerns. Several methods have been developed to estimate maximal oxygen consumption from measurements made at submaximal exercise intensities, but their accuracy is limited and their validity questionable (10,11). Resting values of heart rate are more increased than oxygen uptake while maximal values are not markedly influenced by pregnancy (113, Chapter 2). This suggests that pregnancy alters the relationship between heart rate and oxygen uptake, most notably at low exercise intensities. Therefore, pregnancy may affect the validity of the two methods most commonly used to estimate maximal oxygen uptake from submaximal values: the Åstrand nomogram and the technique of linear extrapolation of the heart rate - oxygen uptake line.

The study that will be described in this chapter was designed to assess the accuracy and validity of estimated values of maximal heart rate and oxygen uptake in pregnant and postpartum women.

4.2 MATERIAL AND METHODS

The study was performed in the 33 healthy women, described in Chapter 2. Details of the study protocol, and data on maximal oxygen uptake, carbon dioxide output, and ventilation, and on maternal and fetal cardiovascular responses were reported in Chapters 2 and 3.

For the purpose of the present study maximal heart rate was estimated as HRest.max = 220-age (yr) beats.min^{-1} (113). Maximal oxygen uptake was estimated in three ways: 1. by using Åstrands nomogram: $\dot{V}O_2est.max_1$ = 100 $\dot{V}O_2$/(0.769HR -56.1), with values of oxygen uptake measured at a heart rate of 138 beats.min^{-1} which represents 50% $\dot{V}O_2max$ (10), 2. by linear extrapolation to estimated maximal heart rate of the linear regression line of the individual values of heart rate and oxygen uptake measured between 30 and 70% $\dot{V}O_2max$: $\dot{V}O_2est.max_2$ = (HR est.max-intercept)/slope, and 3. by linear extrapolation to measured maximal heart rate of the linear regression line of the individual

values of heart rate and oxygen uptake measured between 30 and 70% $\dot{V}O_2$max: $\dot{V}O_2$est.max$_3$ = (HRmax-intercept)/slope.

For each test period mean values and standard errors of the means were computed for heart rate and oxygen uptake. Friedmans test for multiple comparisons and Students paired t-test were used to assess differences between paired variables; a p-value of < 0.05 was taken as the level of significance. Linear regression analysis was applied to assess the relationship between values of heart rate and percentage maximal oxygen uptake (SPSS/PC 2.0). Also linear regression analysis was applied separately to values obtained below and above 70% $\dot{V}O_2$max to test the assumption, inherent in $\dot{V}O_2$est.max$_2$ and $\dot{V}O_2$est.max$_3$, that the slope of the HR-% $\dot{V}O_2$max line is independent of exercise intensity.

4.3 **RESULTS**

Mean values of heart rate and oxygen uptake at rest are shown in Table 4.1. Resting values of heart rate and oxygen uptake on the bicycle ergometer

Table 4.1. Effect of pregnancy on values of heart rate (beats.min^{-1}) and oxygen uptake (L.min^{-1}) at rest.

	trimester 1	trimester 2	trimester 3	postpartum
Bicycle				
heart rate	87±2$^+$	89±2*	94±2*	83±2
oxygen uptake	0.29±.01$^+$	0.29±.01*	0.31±.01*	.27±.01
Treadmill				
heart rate	102±3*	102±3*	104±2*	97±3
oxygen uptake	0.30±.01$^+$	0.32±.01*	0.34±.01*	.29±.01

Values are means±SE; $^+p < 0.05$ and $*p < 0.01$ compared with postpartum control values, n=33.

increased with advancing gestational age to values at 35 weeks' gestation of 13% and 14%, respectively, above the postpartum control values. Values of heart rate and oxygen uptake obtained while the subjects were standing on the treadmill, after 55 minutes of recovery from bicycle exercise, were higher by 14 and 8%, respectively, than the values obtained before bicycle exercise. Mean values of maximal heart rate and oxygen uptake are shown in Table 4.2. Compared with postpartum values, values of maximal heart rate were significantly lower by about 2% during pregnancy, whereas maximal oxygen uptake was unaffected by gestation, both during bicycle and treadmill exercise. Maximal values of heart rate and oxygen uptake during treadmill exercise were consistently higher than those obtained during bicycle exercise, with a mean difference of 3 and 10%, respectively.

Table 4.2. Effect of pregnancy on values of maximal heart rate (HR,beats.min^{-1}) and oxygen uptake ($\dot{V}0_2$,L.min^{-1}).

	trimester 1	trimester 2	trimester 3	postpartum
Bicycle				
HR_{max}	174±2*	174±2*	174±2*	178±2
$\dot{V}O_{2max}$	2.20±.08	2.16±.08	.15±.08	2.19±.08
$\dot{V}O_{2est.max\ 1}$	2.65±.14°	2.59±.12°	2.49±.11°*	2.69±.11°
$\dot{V}O_{2est.max\ 2}$	2.29±.10	2.28±.09	2.27±.09	2.20±.08
$\dot{V}O_{2est.max\ 3}$	2.00±.08°	1.97±.07°	1.95±.08°	2.00±.07°
Treadmill				
HR_{max}	180±2*	178±2*	178±2*	183±2
$\dot{V}O_{2max}$	2.45±.08	2.38±.09	2.33±.09	2.39±.08
$\dot{V}O_{2est.max\ 1}$	2.35±.16	2.29±.16	2.29±.14	2.45±.13
$\dot{V}O_{2est.max\ 2}$	2.39±.09	2.39±.09	2.40±.10	2.26±.08
$\dot{V}O_{2est.max\ 3}$	2.15±.07°	2.13±.07°	2.11±.07°	2.12±.07°

Values are means±SE; *$p < 0.01$ compared with postpartum values, °$p < 0.01$ for estimated values compared with measured values, n=33.
See method section for explanation of terms.

When linear regression analysis was applied to all values of heart rate and exercise intensity expressed as $\%\dot{V}O_2max$, the relationship was significant and the correlation high for bicycle and treadmill exercise in all test periods, with r-values ranging from 0.88 to 0.94. The intercept of the HR-$\%\dot{V}O_2max$ regression line showed a progressive increase with advancing gestational age, and the slope decreased. Therefore, the most marked changes were observed at 35 weeks' gestation (Figure 4.1).

The assumption, inherent in linear extrapolation, was tested, that the slope of the HR-$\%\dot{V}O_2max$ line is unaffected by exercise intensity. When linear relationships were calculated separately for values between 30 and 70% $\dot{V}O_2max$ and for values between 70 and 100% $\dot{V}O_2max$, the slope of the line was found to be reduced at the higher exercise intensity in 233 of a total of 264 tests; the change was significant for both bicycle and treadmill exercise in all test periods. Therefore, the relationship between heart rate and exercise intensity can be described more accurately by a bilinear curve. This is shown in Figure 4.2 for the postpartum period and for 35 weeks' pregnancy. In the postpartum period, the slope of the HR-$\%\dot{V}O_2max$ curve changed at 70% $\dot{V}O_2max$ from 1.30±0.04 to 0.86±0.05 during bicycle exercise and from 1.20 to 0.73±0.04 during treadmill exercise; at 35 weeks' gestation it changed from 1.11±0.04 to 0.70±0.03 during bicycle exercise and from 1.02±0.05 to 0.68±0.03 during treadmill exercise. Pregnancy did not affect the change in slope of the HR-$\%\dot{V}O_2max$ relationship at 70% $\dot{V}O_2max$.

Measured maximal heart rate decreased significantly with age as HRmax = -0.39 age + 189.5 beats. min^{-1}, but the correlation was weak (r=0.15) over the

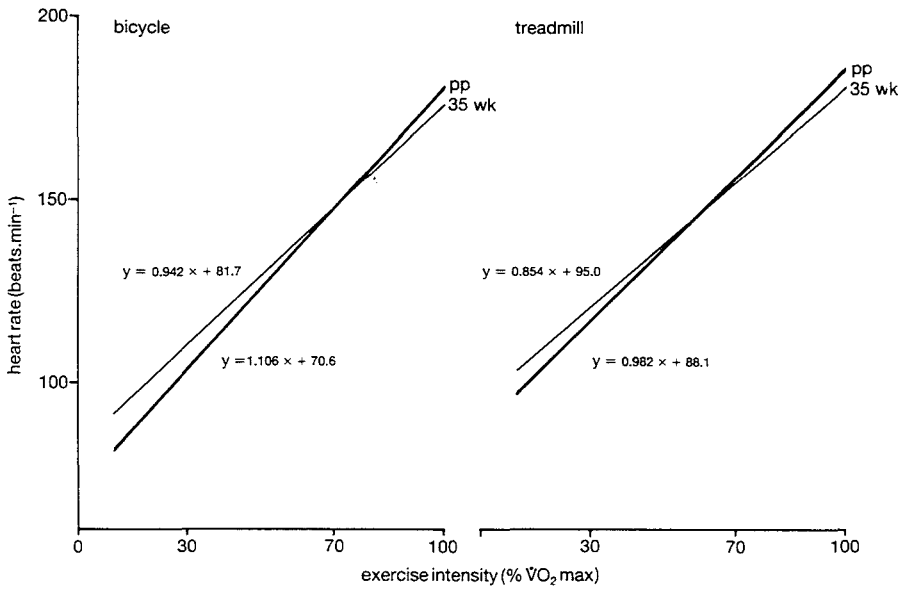

Figure 4.1 Linear relationship between heart rate and exercise intensity (%$\dot{V}O_2$max).

small range of ages (24 to 41 years). Estimated maximal heart rate (220-age) showed an equally weak correlation with measured maximal heart rate as did measured maximal heart rate with age. Average HRest.max was 189±1 beats. min^{-1} and overestimated measured HRmax by 8% during bicycle and by 5% during treadmill exercise.

Mean values of estimated maximal oxygen uptake are presented in Table 4.2. $\dot{V}O_2est.max_1$ (Åstrand method) consistently overestimated $\dot{V}O_2max$ during bicycle exercise (+20%) but not during treadmill exercise (-2%). The Åstrand relationship between HR and %$\dot{V}O_2max$ (10) is presented in Figure 4.2; the line shows a parallel shift to the left compared with the data obtained in the postpartum period during bicycle exercise, whereas during treadmill exercise it is superimposed upon the postpartum data (not shown). Mean values of $\dot{V}O_2est.max_2$ (linear extrapolation to HRest.max) were not significantly different from measured $\dot{V}O_2max$. $\dot{V}O_2est.max_3$ (linear extrapolation to measured HRmax) consistently underestimated $\dot{V}O_2max$ by an average of 9% during bicycle exercise and 10% during treadmill exercise.

Figure 4.3 shows the mean relative errors of estimated values of maximal oxygen uptake. As shown by the large standard deviations, individual errors were large in all tests. They were most pronounced in $\dot{V}O_2est.max_1$ with an average standard deviation of 20% during bicycle and 28% during treadmill exercise. The errors in $\dot{V}O_2est.max_2$ were less pronounced with standard deviations of 17% for bicycle and 21% for treadmill exercise. The least pronounced errors were found in $\dot{V}O_2est.max_3$, where the standard deviations averaged 9% and 10% during bicycle and treadmill exercise, respectively. The

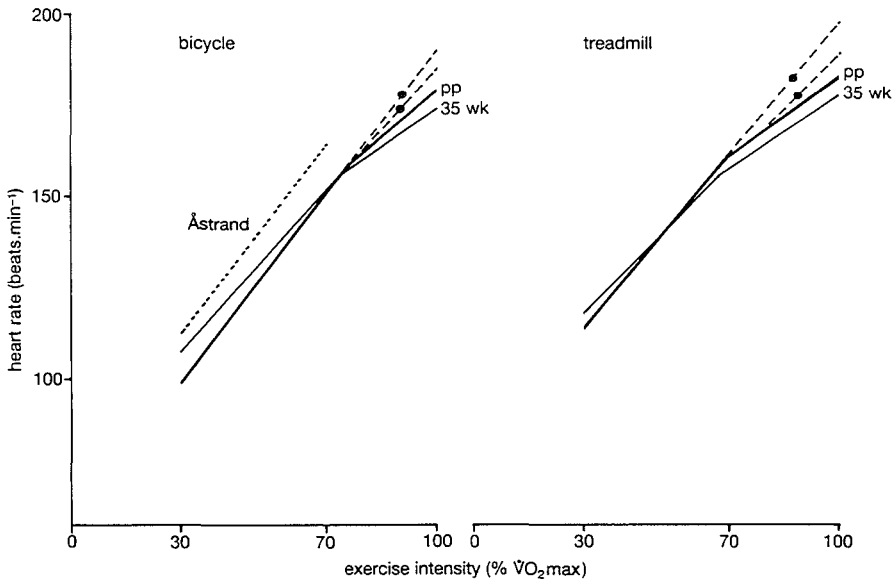

Figure 4.2 Reduced slope of the linear relationship between heart rate and percentage maximal oxygen uptake at exercise intensities above 70% $\dot{V}O_2$max. The interrupted lines represent the linear extrapolation to 100% $\dot{V}O_2$max of values measured between 30 and 70% $\dot{V}O_2$max. The dots represent measured values of maximal heart rate. The dotted line represents Åstrands nomogram for bicycle exercise, for treadmill exercise it is superimposed upon the postpartum line.

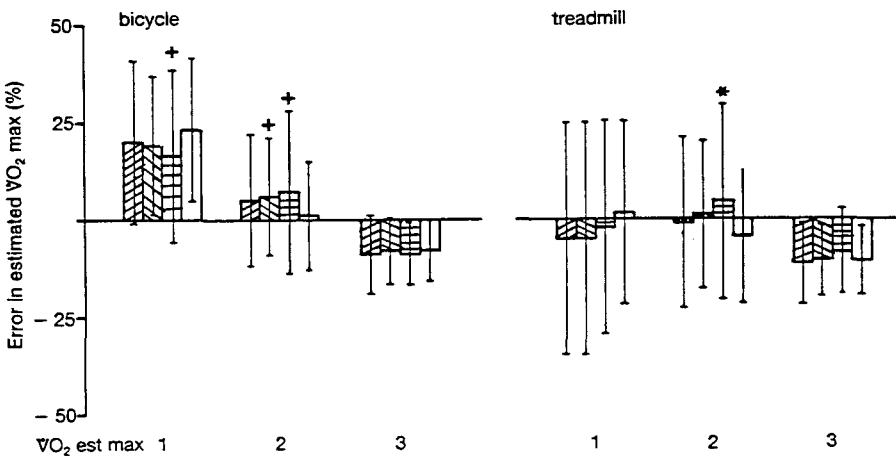

Figure 4.3 Errors in estimated $\dot{V}O_2$max (means ± SD) expressed as a percentage of measured $\dot{V}O_2$max at 16 weeks' ▨, 25 weeks' ▧, 35 weeks' ▤ and postpartum □. + $p < 0.05$, * $p < 0.01$ compared with postpartum values, n=33. The methods used to estimate $\dot{V}O_2$max are explained in the text.

mean error of $\dot{V}O_2$est.max$_1$ tended to decrease with advancing gestational age; it was significantly smaller during third trimester bicycle exercise than in the postpartum period. This was associated with a significant, but apparently false, reduction in $\dot{V}O_2$est.max$_1$ with advancing gestational age. The errors in $\dot{V}O_2$est.max$_2$ during bicycle and treadmill exercise were larger during late pregnancy than in the postpartum period without markedly affecting the average values. The magnitude of the errors in $\dot{V}O_2$est.max$_3$ was not influenced by pregnancy.

4.4 **DISCUSSION**

The Åstrand nomogram is widely used to estimate maximal oxygen uptake in individuals from values of heart rate and oxygen uptake measured between 30 and 70% $\dot{V}O_2$max, and the same nomogram is used for bicycle and treadmill exercise (10). The nomogram is based on results obtained in 31 well-trained women, 20-30 years of age. Variation in individual estimates was reported to be large, with a standard deviation varying between 9.4 and 14.4% for bicycle exercise. The errors were reported to be smaller during treadmill exercise than during bicycle exercise in man, but data were not presented for treadmill exercise in women (10). Åstrand emphasized that further research was needed to decide whether or not the nomogram could also be applied to individuals other than 20-30 years old well-trained women, and warned that individual predictions would be inaccurate (11). In the present study, individual errors were even larger than those reported by Åstrand. This was probably caused by the wider range of body weights and fitness levels in these women, and by the more rapidly incremental exercise protocol used in this investigation. The data from this study confirm that the Åstrand nomogram is unsuitable to predict the $\dot{V}O_2$max of individual women. This is true also during pregnancy.

The Åstrand line was superimposed upon the HR-%$\dot{V}O_2$max line derived from the postpartum women during treadmill exercise. During bicycle exercise, the Åstrand line is shifted parallel to the left of the HR-%$\dot{V}O_2$max line (Figure 4.2). This illustrates the consistent overestimate of $\dot{V}O_2$est.max$_1$ during bicycle exercise. The parallel shift may be explained by the known fact that heart rates are lower on the bicycle ergometer than on the treadmill, both at rest and during exercise. Apparently, the same nomogram cannot be applied to both bicycle and treadmill exercise.

One could argue that even though individual estimates of maximal oxygen uptake may be inaccurate, such methods could still be useful to study groups of individuals. However, in contrast to the single study previously reported on this subject (113), it was found that the application of Åstrands nomogram lead to the erroneous impression that $\dot{V}O_2$max decreases with advancing gestation during bicycle exercise. This may be explained by the change in the HR-%$\dot{V}O_2$max line with advancing gestational age, as shown in Figure 4.2.

At 35 weeks' gestation the intercept of that line is larger and the slope is smaller compared with that in the postpartum period. For that reason, the distance from the Åstrand line to the measured line is smaller at 35 weeks' than postpartum.. As a consequence, the mean error shown in Figure 4.3 is smaller at 35 weeks, which results in the observed reduction in mean $\dot{V}O_2$est.max$_1$. These findings demonstrate that Åstrands nomogram can not be applied reliably to pregnant women exercising on the bicycle ergometer.

The average values of $\dot{V}O_2$est.max$_2$ were not significantly different from measured $\dot{V}O_2$max. This was also found in the single previous study on the value of $\dot{V}O_2$max prediction in pregnant women (113). It was concluded from that study that the extrapolation of the HR-%$\dot{V}O_2$max curve, from values obtained below 70% $\dot{V}O_2$max to an estimated maximal heart rate, is the most accurate method of predicting $\dot{V}O_2$max in pregnant women. However, such an extrapolation is legitimate only when the slope of the HR-%$\dot{V}O_2$max line is unaffected by exercise intensity, which is not the case. The apparent accuracy results from two opposing errors. First, HRest.max, calculated as 220-age (yr), consistently overestimates measured maximal heart rate by an average of 8% during bicycle exercise and 5% during treadmill exercise. Consequently, the linear extrapolation of values of HR and $\dot{V}O_2$ between 30 and 70% $\dot{V}O_2$max should result in a similar overestimate of maximal oxygen uptake. This is illustrated in Figure 4.2 by the interrupted lines. Second, linear extrapolation of the HR-%$\dot{V}O_2$max line to measured maximal heart rate ($\dot{V}O_2$est.max$_3$) consistently underestimates $\dot{V}O_2$max, by 9% and 10% during bicycle and treadmill exercise, respectively. This is because the bilinear HR-%$\dot{V}O_2$max relation is not taken into account and, therefore, measured maximal heart rate cuts off the extrapolated HR-%$\dot{V}O_2$max line at approximately 90% $\dot{V}O_2$max. This observation is independent of pregnancy. $\dot{V}O_2$est.max$_3$ was introduced only to demonstrate the above error and can not be used to predict $\dot{V}O_2$max because it consistently underestimates true $\dot{V}O_2$max.

Because of fetal health concerns, exercise is often limited to submaximal intensities in pregnant women. In Chapter 1 it has been argumented why it seems unlikely that even strenuous maternal exercise will jeopardize fetal health. Three groups have studied maximal oxygen uptake in pregnant women (7,113, Chapter 3). All women participating in these studies apparently delivered of healthy infants. In the first study, it was noted that during exercise 3 of the fetuses of the 88 exercising women showed bradycardia; after exercise fetal heart rate was found slightly increased (7). The second study reported one episode of fetal bradycardia during exercise and 15 episodes of transient bradycardia ($>$ 10 s) after 80 maximal exercise tests in 40 women. As described in Chapter 3, fetal heart rate could not be obtained reliably during excercise. During recovery from exercise a significant increase in mean fetal heart rate of 4 beats.min^{-1} was observed. The increase in fetal heart rate after exercise was interpreted as a result of increased body temperature and not of hypoxia,

because other possible signs of hypoxia, such as reduced variability, loss of accelerations or decelerations of fetal heart rate were not observed. Because of the inaccessibility of the human fetus it is impossible to answer conclusively the question as to how safe strenuous maternal exercise really is in humans.

Because the above methods to estimate maximal oxygen uptake cannot replace the measurement of $\dot{V}O_2max$ and the data suggest that maximal oxygen uptake can safely be measured in healthy pregnant women, it is recommended that, for research purposes, maximal oxygen uptake be determined rather than estimated in pregnant women.

Chapter 5

PHYSIOLOGY AND PRACTICAL IMPLICATIONS OF DYNAMIC EXERCISE IN PREGNANCY

5.1 INTRODUCTION

In pregnancy the uterus and its contents constitute a growing mass of tissue with an increasing need for oxygen and substrates. Muscle activity is associated with an even more dramatic increase in metabolic demands. One might question if the physiological adaptations are adequate to provide for the combined demands of exercise and pregnancy.

Most recent studies on the physiology of exercise during pregnancy have focussed on maternal aspects, and data from those studies will be reviewed in this chpater. In contrast, not much new information has become available on the effects of maternal physical exercise on the fetus. A recent and extensive review (84) provides evidence that even strenuous physical exercise does not harm the fetus, at least not in healthy mothers with uncomplicated pregnancies.

The study of physiological adaptations to exercise during human pregnancy is difficult for several reasons. First, pregnancy has a marked effect on many physiological variables at rest and may aggrevate the already wide variation among individuals in physical fitness, body weight and composition, and motivation, that may affect exercise responses. Second, many physiological studies cannot be performed in humans because of invasive techniques required. Third, different types of exercise may elicit different physiological responses. It is customary to distinguish between dynamic and static exercises. In dynamic exercise muscular activity results in body movement, whereas in static exercise it does not. Dynamic exercises can be divided in weightbearing and nonweightbearing activities. In weightbearing activities, such as treadmill exercise, the physiological burden of the test increases with body weight, whereas in nonweightbearing activities, including bicycle exercise, it is unaffected by body weight.

This review will explore what is known and not known about the physiological adaptations to exercise stress superimposed upon the changes of pregnancy. It will focuss on maternal responses in humans, supplemented by animal data only when considered relevant for the understanding of physiological mechanisms. In particular, the following questions will be addressed: 1. to what extent are the acute effects of dynamic exercise in pregnant women different from those in nonpregnant women? 2. to what extent does pregnancy affect physical training? and 3. how relevant is all of this to pregnant sportswomen with regard to their physical activity? The discussion will be limited to dynamic exercise because responses in pregnant women to static exercise have hardly been explored.

5.2 OXYGEN UPTAKE

Almost all energy at rest is generated by oxydative degradation of nutrients (11). Oxygen uptake at rest is influenced by individual factors such as species, body size and composition, sex, and age (24). Also temporary circumstances such as nutritional status, body position, and environmental factors (e.g. temperatureand humidity) affect resting oxygen uptake (24). Under basal conditions the nonpregnant adult uses energy exclusively for the maintenance of vegetative functions and heat production. During pregnancy additional oxygen and nutrients are needed for the growth, metabolism, and muscular activity of the fetus, and for the alterations in maternal body composition, including the accumulation of fat. Resting oxygen uptake shows a linear increase with advancing gestational age and near term reaches a maximum of 13 to 33% above the level in nonpregnant controls (26,103). It is known from experiments in chronically instrumented pregnant sheep that of a total rise in resting oxygen uptake of 20% near term, approximately 16% is taken up by the pregnant uterus while maternal oxygen uptake per se is increased by only 4% (29). This suggests that the increase in maternal cardiac output and ventilation at rest that occurs during pregnancy has little importance for maternal energy requirements.

Because only a limited amount of energy can be produced anaerobically, the ability of a person to perform exercise of longer duration depends largely on the capacity of aerobic energy production. Therefore, maximal oxygen uptake is the best indicator of an individual's ability to perform endurance exercise. It is often expressed per unit of body weight, surface area, or lean body mass, to indicate the level of physical fitness independent of differences in body size between individuals. Such normalization of maximal oxygen uptake should not be applied to pregnant women, because the increase in body weight during pregnancy is the result of the growing fetal and placental mass, and the accumulation of amniotic fluid, body fluids and fat, whereas muscle mass remains unchanged. Therefore, normalization of maximal oxygen uptake for body weight in pregnant women will lead to the erroneous conclusion that physical fitness is reduced in pregnancy (84).

Does pregnancy have an effect on the ability to perform physical exercise? It has been suggested that venous return and cardiovascular reserve decline progressively with advancing gestational age, thereby reducing exercise performance (97,121). In contrast, it has been argued by others that maximal oxygen uptake could increase during pregnancy as a result of a training effect induced by pregnancy weight gain (80,84). In an attempt to solve this question maximal oxygen uptake was measured in pregnant women in two recent studies reported in the literature (7,114) and in the study described in Chapter 2 (Figure 5.1). In the first study, 25 women in the late second or early third trimester of pregnancy were compared with 10 nonpregnant controls (7). Maximal oxygen uptake during treadmill exercise was reported to be 12% lower in the pregnant

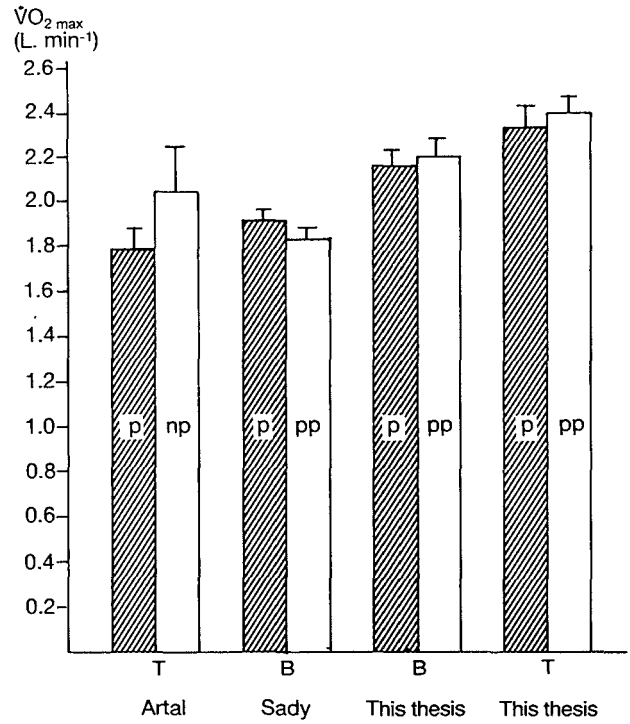

Figure 5.1 Measured values of maximal oxygen uptake in pregnant women and controls as reported in literature, and in the study described in Chapter 2 of this thesis. P=pregnant, PP=postpartum, NP=nonpregnant, B=bicycle, T=treadmill.

women than in the controls (1.79±0.09 L.min^{-1} and 2.04± 0.2 L.min^{-1}, respectively). It should be noted that the results of this study may be affected by methodological flaws. The study was cross-sectional in design, so that a difference in fitness level between the study groups rather than the pregnancy itself could be responsible for the observed difference in maximal oxygen uptake. In addition, it is possible that the pregnant women gave up exercise sooner than the nonpregnant controls because maximal exercise was defined as symptom-limited without objective verification of the maximum, e.g. by monitoring maximal heart rates. Sady et al. (114) have studied maximal oxygen uptake during bicycle exercise longitudinally in pregnancy and in the postpartum period in conditions of objectively confirmed maximal effort. In this study, as well as in the study reported in Chapter 2 of this thesis, no significant differences were found between pregnant and postpartum women during bicycle and treadmill exercise. Because it could have been argued that the postpartum values do not represent the true nonpregnant state, it was further demonstrated that values of maximal oxygen uptake obtained 7 or 8 weeks postpartum were not significantly different from those obtained before pregnancy (Chapter 2 of this

thesis) or 6 months after delivery (115 and Chapter 2 of this thesis). As reported in Chapter 2, and shown in Figure 5.1 values of maximal oxygen uptake during treadmill exercise were consistently about 10% higher than those obtained during bicycle exercise, both in pregnancy and postpartum. This most likely results from the use of a larger muscle mass during treadmill exercise (11).

When resting values of oxygen uptake during pregnancy are increased and maximal oxygen uptake does not differ between pregnant and postpartum women, the oxygen available for exercise (exercise minus rest) should be reduced during pregnancy. However, no significant difference in oxygen availability for exercise was found between pregnant and postpartum women (114, Chapter 2). This may be explained by the insensitivity of the method of measurement. Oxygen uptake in pregnancy increases by 11 to 20% in the resting state while it increases about 1000% during maximal effort. The reduction in the amount of oxygen available for maximal exercise would therefore be in the order of magnitude of 1 to 2%. Such a small difference cannot be detected; it also seems to be of little physiological significance.

Oxygen uptake during submaximal exercise in pregnancy is markedly influenced by exercise intensity, resting oxygen uptake, and body weight. Table 5.1 summarizes the results of controlled studies of oxygen uptake during submaximal exercise in pregnancy. When exercise intensity increases, the contribution of oxygen uptake at rest to the total uptake of oxygen during exercise decreases from about 20% at minimal effort to 1% at maximal effort. Therefore, the known increase in resting oxygen uptake during pregnancy will affect total oxygen uptake most markedly at low levels of exercise intensity. Body weight gain has no marked influence on oxygen uptake during non-weightbearing exercise, but it increases the burden, and consequently the oxygen uptake, of every weightbearing task. This does have an important influence on the results of exercise studies performed on a treadmill. Most studies report the level of submaximal treadmill exercise in terms of speed and inclination. However, the same treadmill setting will represent a higher physiological burden in women with a higher body weight. To permit comparisons of physiological variables between pregnant and nonpregnant individuals with differences in body weight and fitness level, the exercise burden must be expressed in physiological terms such as the percentage of maximal oxygen uptake (%$\dot{V}O_2$max).

Maximal oxygen uptake is often not measured but estimated by extrapolation from values measured at submaximal levels. As shown in Chapter 4, such estimates are inaccurate. Therefore, measured maximal oxygen uptake remains the gold standard.

5.3 CIRCULATION

Maternal hemodynamic changes in pregnancy have recently been reviewed (129). Uterine and systemic vascular resistances decrease and blood volume

Table 5.1. Controlled studies of oxygen uptake during submaximal exercise in pregnancy.

First author	year	pregnant women (n)	study design (L,C)	type of exercise (B,H,S,T)	pregnancy change
Eismeyer (52)	34	12	C	B	=
Effkeman (51)	38	26	C	H	↓
Widlund (135)	45	157	C	B	↑
Guzman (21)	70	8	L	B	↑ =
Ueland (62)	73	6	L	B	↑
Knuttgen (77)	74	13	L C	B T	↑ =
Pernoll (103)	75	12	L	B	↑
Lehmann (81)	76	10	L C	B	↑
Edwards (50)	81	20	L	B	↑
Dibblee (44)	83	16	L	S	↑ =
Schweingel (126)	84	25	C	B	↑ = ↓
Kusche (80)	86	14	L	B	↑
Kulpa (78)	87	85	L	B T	=
McMurray (90)	88	12	L	B	= ↓
Williams (136)	88	10	C	S	=
Clapp (35)	89	18	L	T	↑
Carpenter (26)	90	10	L	B T	↑

L:longitudinal, C:cross-sectional, B:bicycle, H:handcrawl, S:steptest, T:treadmill.

increases during pregnancy in adaptation to the metabolic needs of the growing fetus with cardiac output increasing markedly with little change of blood pressure. The exact pattern of physiological changes in circulating blood volume and hemodynamic variables is still not known, mainly due to a lack of serial studies throughout normal pregnancy. There is reasonable agreement that pregnancy in a woman at rest is associated with a rise in cardiac output of approximately 1.5 $L.min^{-1}$, achieved by a rise in heart rate of approximately 15 $beats.min^{-1}$ and an increase in stroke volume of 15-20 ml. Of the increase in cardiac output about 45% reaches the uterus, 30% goes to the kidney, and most of the remaining 25% is distributed to the skin. It should be noted that posture may have a marked effect on cardiovascular variables in pregnancy. The sitting and upright positions require muscular activity to maintain body position; in the supine position, blood is pooled in the lower extremities and venous return may be reduced when the pregnant uterus obstructs blood flow in the inferior vena cava (120).

During exercise, cardiac output shows a linear increase with oxygen uptake and exercise intensity, but it may level off at high values (11). In spite of the many methodological problems associated with the measurement of cardiac output (129), the results of most studies indicate that cardiac output increases to the same extent in pregnant and nonpregnant women at similar levels of exercise (26,62,77,96,114,115,121) (Table 5.2). Absolute values of cardiac output

Table 5.2. Cardiac output in pregnancy at rest and during exercise as compared to nonpregnant controls.

First author	year	pregnant women (n)	study design	type of exercise	rest	exercise	exercise minus rest
Ueland (121)	69	11	L	B	↑	↑	=
Guzman (62)	70	8	L	B	?	↑	=
Knuttgen (77)	74	13	L	B T	?	=	=
Morton (96)	85	23	L	B	=	=	=
Sady (114)	89	39	L	B	↑	↑	=
Sady (115)	90	9	L	B	↑	↑	=
Carpenter (26)	90	10	L	B T	↑	↑	=

L:longitudinal, B:bicycle, T:treadmill.

at near maximal levels of exercise have been reported to be 15% higher during pregnancy than in the postpartum period (114). This could reflect the reported higher maximal stroke volume during pregnancy in the absence of a change in maximal heart rate (114), and suggests that the ability to exercise during pregnancy is not primarily limited by the cardiovascular system.

Values obtained at submaximal levels of exercise reflect the resting values and the increases that are determined by the level of the exercise intensity. Although two groups of investigators found lower values of heart rate (80,126) and one reported lower values of stroke volume in pregnant than in nonpregnant women during submaximal exercise (96), all others reported unaltered or slightly elevated values of heart rate (26,62,77,81,89,113,114, 115,121) and stroke volume (26,62,114,115) during submaximal exercise in pregnant women compared with values observed in nonpregnant controls.

Plasma volume decreases temporarily during exercise probably as a result of increased hydrostatic pressure in the exercising muscles (61). In man, the reduction in plasma volume is proportional to exercise intensity, with a maximum reduction of 15-18% at 65% $\dot{V}O_2$max (61). A 20% reduction in plasma volume was found in pregnant sheep during strenuous exercise (82). It seems likely that similar changes may occur in pregnant women, but it is unknown if the quantitative response in human pregnancy is comparable to that observed in pregnant animals.

As shown in Chapter 3, mean arterial pressure increases by about 17% in pregnant and postpartum women during strenuous bicycle exercise at approximately 75% $\dot{V}O_2$max. The increase in mean arterial pressure during exercise reflects a marked increase in systolic pressure in the absence of a change in diastolic pressure, and indicates that the increase in cardiac output during exercise is more pronounced than the reduction in vascular resistance. Pregnancy has no marked effect on the blood pressure response to strenuous bicycle exercise (114 and Chapter 3). Some investigators observed slightly higher systolic pressure values at lower levels of exercise intensity during pregnancy

(18,40,54, 126), whereas others found no difference between pregnant and nonpregnant women (44,81,96,114, Chapter 3). The available evidence suggests that the blood pressure response to exercise is little or not at all affected by pregnancy. The cardiovascular responses to exercise in pregnancy, as discussed in the previous paragraphs, are summarized in Table 5.3.

Table 5.3. Cardiovascular changes in pregnancy at rest and during exercise.

	Pregnancy*	Exercise*	Exercise in pregnancy**
Cardiac output	↑	↑	↑
Heart rate	↑	↑	=
Stroke volume	↑	↑	↑
Blood volume	↑	↓	=
Mean blood pressure	= ↓	↑	=

Compared to nonpregnant values at rest (*) and during exercise (**)

Cardiac output is redistributed during exercise. Vasodilatation occurs in exercising muscles, probably mediated by local metabolic factors, and in the skin (11). Vasoconstriction in other tissues is most likely mediated by the sympathetic system and involves the splanchnic bed, the nonworking muscles (11), and the pregnant uterus (82). The perfusion of the human pregnant uterus has been estimated to decrease by 25% during mild exercise in supine position (95). This conclusion was drawn from the disappearance of ^{25}Na injected into the myometrium, and probably should be considered an overestimate because myometrial flow decreases more markedly during exercise than does the flow to the cotelydons (66). With the use of the $^{133}Xenon$-technique it was found that placental blood flow was similar before and after exercise (111). Doppler ultrasound studies showed that the blood flow velocity in the uterine arteries was similar before and after moderate bicycle exercise (15,47,93,118). These measurements must be interpreted with caution because they were not made during but after exercise. Experiments in chronically catheterized sheep have demonstrated that uterine blood flow decreases with the level and to a lesser extent also with the duration of exercise, to return rapidly to control values when exercise is discontinued (Figure 5.2) (82). Despite the reduction in uterine blood flow, uterine oxygen uptake does not change significantly during prolonged treadmill exercise in sheep (27,30,83), most likely due to redistribution of blood flow within the uterus, hemoconcentration, and increased O_2 extraction (83).

Little is known about the effect of pregnancy on the exercise-induced redistribution of flow to other organs. It has been reported that femoral artery flow in pregnant women is increased during recovery from bicycle exercise and that cerebral blood flow is unaffected (15). However, the study was uncontrolled and it remains unclear if the responses were quantitatively different

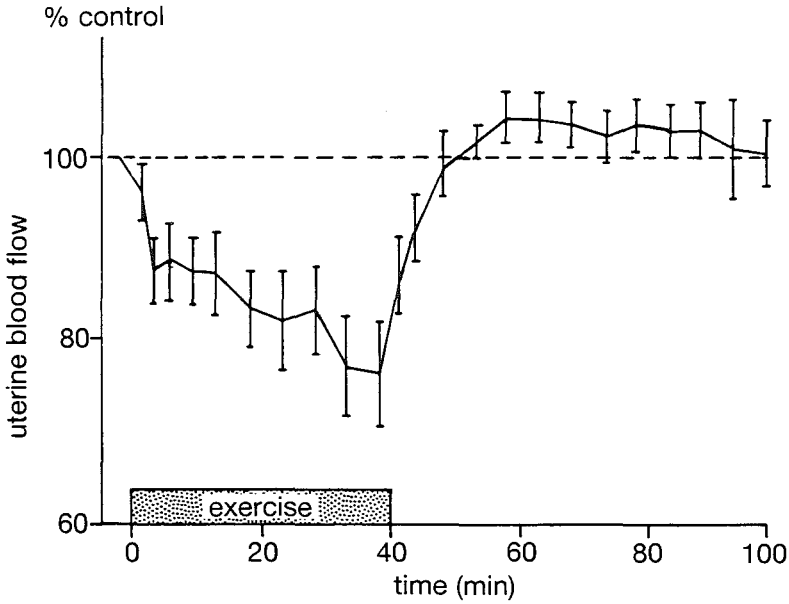

Figure 5.2 Uterine blood flow response to exercise at 70% $\dot{V}O_2$max in pregnant sheep (after Lotgering et al.[82])

from those in nonpregnant women. The results of another study suggest that visceral blood flow decreases more markedly during exercise in pregnant than in nonpregnant women, because urinary 5-hydroxy indolacetic acid following exercise was more reduced in pregnant women than in nonpregnant controls (46). Early observations suggested that renal plasma flow increased during exercise in pregnant women (134), but studies in pregnant sheep and goats failed to show significant changes in renal blood flow (17,66). For further information about redistribution of blood flow during exercise in pregnancy we must rely on data obtained in animals because no human data are available. In pregnant sheep, exercise was shown to induce an increase in blood flow to the exercising muscles, respiratory muscles, and adipose tissue, while blood flow to the gastrointestinal tract, spleen, pancreas and uterus decreased (17). These results were quantitatively similar to those observed earlier in nonpregnant sheep (17), which suggests that pregnancy does not markedly alter the response to exercise. In conclusion, results of animal experimental studies suggest that cardiac output redistribution during exercise is not markedly affected by pregnancy, except for the reduction in uterine blood flow.

5.4 VENTILATION AND BLOOD GASES

The changes in ventilatory function that occur in pregnancy have been exten-

sively reviewed (21,133). Pregnancy appears to be associated with hyperventilation, which is generally considered a progesterone effect (91). Figure 5.3 summarizes the changes in respiratory volumes in pregnancy at rest and during exercise. In the last trimester of pregnancy, the configuration of the rib cage is altered by the elevation of the ribs and the increase in chest circumference (7). Residual volume, expiratory reserve volume, functional residual capacity, and total lung capacity at rest decrease, whereas the inspiratory capacity and inspiratory reserve volume increase (99). As a net result the vital capacity remains constant and tidal volume increases. Minute ventilation at rest increases with gestational age to values near term that are about 30% higher than in nonpregnant women (50 and Chapter 2 of this thesis). This increase must result completely from the larger tidal volume because ventilation frequency is unaffected by pregnancy.

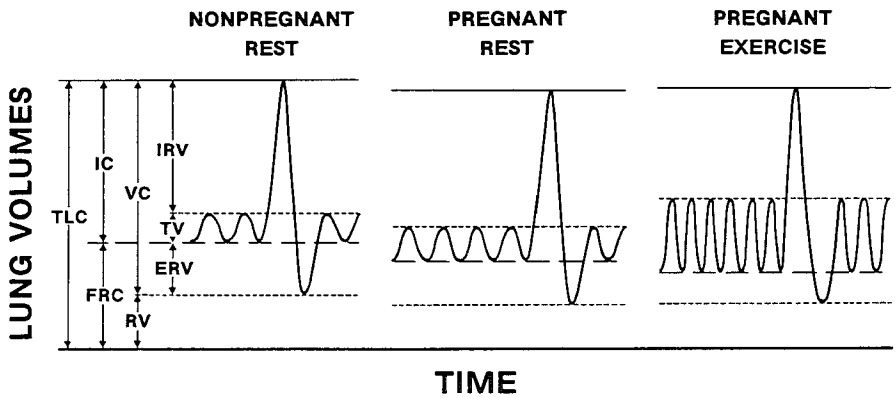

Figure 5.3 Changes in long volumes during pregnancy (modified after Novy and Edwards [99]) and exercise. TLC=Total long capacity, IC=Inspiratory capacity, FRC=Functional residual capacity, VC=Vital capacity, RV=Residual volume, ERV=Expiratory reserve volume, TV=Tidal volume.

During exercise in pregnancy, minute ventilation increases with exercise intensity to a maximum value that is approximately eight times the resting value (Chapter 2). Maximal minute ventilation is significantly higher, by about 8%, in pregnant than in nonpregnant women (113,114, and Chapter 2), and again this results from consistently larger tidal volumes in the absence of a difference in ventilation frequency. During submaximal exercise minute ventilation was also reported consistently to be higher in pregnancy than in the nonpregnant state (19,50,51,52,62,77,81,104, 135,136). Ventilation is governed by oxygen consumption, carbon dioxide production, and the pH of the blood (130). The hyperventilation that persists during exercise in pregnancy could result from a change in threshold which may be induced by progesterone as in the resting state.

Carbon dioxide output at rest increases with gestational age to a maximum value near term that is 20 to 38% larger than in nonpregnant controls (104 and Chapter 2 of this thesis). Like the increase in oxygen uptake the rise in CO_2 output mainly reflects the addition of the fetus and placenta to total metabolism. The increase in carbon dioxide output is slightly larger than the increase in oxygen uptake, as indicated by the small but significant rise of about 4 to 9% in respiratory exchange ratio at rest during pregnancy (77,104 and Chapter 2). This may reflect the predominant use of carbohydrates by the fetal placental unit. Carbon dioxide output increases with exercise intensity. In contrast to maximal oxygen uptake, which remains unaltered in pregnancy, maximal carbon dioxide output has been found to decrease gradually with gestational age (Chapter 2). For this reason, the respiratory exchange ratio at maximal exercise is lower during pregnancy than it is postpartum (7,114, and Chapter 2). As discussed in Chapter 2, this may be due to substrate utilization, pH, or oxygen debt, but the relative importance of each of these mechanisms has not been determined. At submaximal levels of exercise carbon dioxide output and respiratory exchange ratio are influenced by the increased resting values and reduced maximal values characteristic of pregnancy. It may be expected that the carbon dioxide output and respiratory exchange ratio tend to be higher during mild exercise, similar during moderate exercise and lower during strenuous exercise in pregnant women than in controls. Data from several studies have shown this to be true (7,50,81,104). These ventilatory changes during pregnancy and exercise are summarized in Table 5.4.

Alveolar ventilation increases by about 30% in pregnancy (104), while the pulmonary diffusing capacity for carbon monoxide remains unchanged (16). The hyperventilation in pregnancy does not affect arterial oxygen tension but results in a reduction in carbon dioxide tension (21,81). The latter is partially compensated by an increased renal excretion of bicarbonate (21,81) resulting in only a small rise in the pH of the blood. During exercise the efficiency of gas exchange increases in nonpregnant individuals, as a result of increased pulmonary diffusing capacity (16), increased alveolar ventilation (9), and a more uniform distribution of ventilation and perfusion (43). These responses are unaffected by pregnancy (16).

Table 5.4. Ventilatory changes in pregnancy at rest and during exercise.

	Pregnancy*	Exercise*	Exercise in pregnancy**
Minute Ventilation	↑	↑	↑
Tidal volume	↑	↑	↑
Ventilation frequency	=	↑	=
Oxygen uptake	↑	↑	=
Carbon dioxide output	↑	↑	↑ ↓
Respiratory exchange ratio	↑ =	↑	↑ ↓

Compared to nonpregnant values at rest (*) and during exercise (**)

Maternal blood gas changes have not been studied during maximal exercise. Arterial oxygen tension has been reported not to change during mild exercise in pregnancy but to increase slightly after exercise (88). Because these observations were uncontrolled, it is unknown if this response is different from that in nonpregnant women. The carbon dioxide tension falls during exercise hyperventilation, and the fall becomes more pronounced when lactate accumulates during heavier and more prolonged exercise (9). In a longitudinal study of maternal blood values during submaximal exercise (81) it was observed that arterial CO_2 tension was slightly lower in pregnant women (32±4 Torr) than in controls (36±5 Torr) at similar levels of exercise. This indicates that pregnancy hyperventilation persists during exercise. At the same time the pH of the blood was marginally lower in pregnant than in postpartum women during moderate exercise owing to the lower bicarbonate concentration and the higher lactate level (81). In conclusion, it appears that, apart from the hyperventilation, pregnancy does not have a marked influence on ventilation or respiration during exercise.

5.5 METABOLISM

At rest, energy is generated by aerobic processes. Therefore, the metabolic rate is directly related to oxygen consumption and the caloric equivalent and relative amounts of the substrates used for combustion (24). The nonprotein respiratory exchange ratio (R) reflects the relative contributions of fat (R= 0.7) and carbohydrate (R=1.0); protein metabolism is often ignored as its contribution is relatively small (< 7%) and constant (24). The respiratory exchange ratio equals about 0,85 with a normal diet in sedentary nonpregnant adults, but may vary from 0.75 to 0.95 depending on the diet (28).

During pregnancy the turnover rate of glucose increases in absolute terms, but it remains constant when normalized for the increase in body weight (76). The mean plasma glucose concentration reflects the balance between production (absorption and gluconeogenesis) and utilization and shows a linear decrease with advancing gestational age (90). Because the amount of muscle glycogen is limited, the plasma glucose concentration decreases only during strenuous and prolonged exercise when liver gluconeogenesis falls short and no additional glucose is taken up (11). The effect of pregnancy on plasma glucose concentrations has not been studied under such strenuous circumstances. Although it has been found in some studies that moderate exercise does not affect plasma glucose concentration (4,8,109), other investigators have reported values after such exercise that were slightly lower during pregnancy than in the control period (18,34,81,90,126). Given the utilization of glucose by the fetoplacental unit and the lower mean plasma glucose levels at rest, it is conceivable that a mechanism analogous to "accelerated starvation" (57) could be responsible for the observed lower plasma concentrations during exercise in pregnancy. Further studies are needed to confirm this concept.

Plasma lactate concentrations at rest have been reported to be higher (18,34,126), unchanged (81,90), or slightly lower (80) in pregnant than in nonpregnant women. Resting lactate levels could be slightly increased in pregnancy because the placenta is an important source of lactate (13). During exercise above the anaerobic threshold the lactate concentration increases with the level and the duration of exercise as a result of lactate production by muscles (11). It is not known whether pregnancy has any effect on lactate production during maximal exercise. In an early study of submaximal exercise, lactate concentrations were found to be higher in pregnant than in nonpregnant women and it was suggested that this could be due to a lower anaerobic threshold in pregnant women (81). It was observed in the same study that the lactate-pyruvate ratio after exercise was higher in pregnant than in postpartum women (81). The lactate-pyruvate ratio may be used as an index of anaerobic metabolism, because pyruvate is an intermediary breakdown product of glucose that can be converted either aerobically to acetyl-co A before entering the Krebs-cycle, or anaerobically to lactate (11). Later studies, however, reported smaller increases in lactate concentrations during exercise in pregnant women than in controls (18,34,80,90, 126) and a similar rise in the lactate-pyruvate ratio in pregnant and nonpregnant women after exercise (18). Therefore, it seems likely that pregnancy does not markedly alter the anaerobic threshold.

Concentrations of triglycerides are higher in pregnant than in nonpregnant women and the variable changes that occur in these concentrations during submaximal exercise seem to be unaffected by pregnancy (18,90,126). However, serum concentrations of triglycerides provide little information about fat metabolism. The observation that the respiratory exchange ratio at maximal exercise is lower in pregnant women than in postpartum controls (114, and Chapter 2 of this thesis) may suggest that pregnant women use fat for combustion more easily than do nonpregnant women.

5.6 **HORMONES**

The blood glucose concentration is largely maintained by the insulin - glucagon ratio and its effect on liver, fat and muscle cells (138). The mean insulin-glucagon ratio is markedly elevated in pregnancy, because mean insulin concentrations are much higher and glucagon concentrations are only slightly increased. The hyperinsulinism of pregnancy results in only small postprandial reductions in plasma glucose concentrations because it is associated with a progressive increase in peripheral insulin resistance (138). During exercise insulin concentrations are unchanged (22) or decreased (119), whereas glucagon concentrations increase, perhaps mediated by catecholamine release (22,119). After submaximal exercise in pregnant women plasma insulin concentrations were found unchanged (4,6), or decreased (75), while a transient increase in plasma glucagon concentration was noticed (4,6). Because these studies were

uncontrolled it remains unknown whether these responses are quantitatively different from those in nonpregnant women.

Growth hormone has anti-insulin properties (119). In one uncontrolled study it was noted that growth hormone levels during mild exercise in pregnancy were not different from those at rest (75). Cortisol increases the formation of carbohydrates from protein. Free plasma cortisol concentrations increase during the course of gestation to values near term that are 3-fold higher than those in nonpregnant women (90). They appear to be unaffected by mild exercise in nonpregnant individuals, but they have been shown to increase at exercise intensities greater than 65% $\dot{V}O_2$max (58). All three studies on plasma cortisol concentrations during exercise in pregnancy were performed at an exercise intensity of less than 65% $\dot{V}O_2$max and in none of these studies a change in cortisol during exercise either in the pregnant or in the nonpregnant women was reported (4,90,108).

Catecholamines increase glyconeogenesis and free fatty acid mobilization in addition to increasing blood pressure (119). Plasma catecholamine concentrations at rest do not change in pregnancy (54), but they increase with the intensity and the duration of exercise in nonpregnant (119) as well as in pregnant women (8). Most studies on catecholamine concentrations during exercise in pregnancy were uncontrolled (4,6,8,105,108). One study showed increases in plasma levels of both norepinephrine and epinephrine that were more marked in pregnant than in nonpregnant women during a mild exercise test (40). Because the test was performed on a treadmill set at a fixed speed and inclination, the larger increase in plasma catecholamines during pregnancy may have been due to a higher workload because of weight gain. Similar increases in the levels of both hormones during moderately strenuous nonweightbearing exercise in pregnant and in nonpregnant women were observed in another study (54). Further studies are needed to determine whether pregnancy really affects the exercise-induced catecholamine response, especially during strenuous exercise.

The renin-angiotensin system constitutes an important regulating mechanism of blood volume and blood pressure. During pregnancy plasma renin activity increases manyfold but the sensitivity of the blood vessels to vasopressor effects of angiotensin is reduced (23). Strenuous exercise increases plasma renin activity in nonpregnant individuals (119). In the only controlled study on this subject, an increase in plasma renin activity was observed during moderately strenuous exercise in postpartum women, but not in pregnant women (54). As suggested by the authors, a possible explanation for this finding could be that the much higher resting levels in pregnancy may mask the increase that normally occurs during exercise (54).

Beta-endorphins cause mood changes and modulate gonadotropin and prolactin secretion (94). Beta-endorphin concentrations are elevated in pregnancy (109) and they have been shown to increase during exercise at intensities of greater than 80% $\dot{V}O_2$max (107). In the single study on beta-endorphin

concentrations during fairly strenuous exercise, similar increases were observed in pregnant and in nonpregnant women (109).

The concentration of prolactin increases during the course of gestation and, although apparently not acutely affected by moderate exercise, it has been reported to increase markedly during recovery in pregnant as well as in nonpregnant women (109). This may explain the observation that lactating women who exercise regularly have a slightly higher volume of breast milk than sedentary controls (85).

The increased coordination of the myometrium during labor is related to the formation of gap-junctions, regulated by steroid hormones and prostaglandins (125). Progesterone is thought to reduce uterine contractility whereas estrogens may stimulate the uterus to contract (125). Plasma concentrations of progesterone and estriol show an enormous rise in the course of pregnancy when they are produced in large quantities by the placenta. Moderately strenuous exercise in pregnancy had no marked effect on the concentrations of progesterone, estradiol and estriol (108).

5.7 **BODY TEMPERATURE**

Despite marked changes in ambient temperature, homeothermic organisms maintain their body temperature at a fairly constant level by the balance of heat production and heat loss. Basal body temperature rises approximately 0.5°C at ovulation. The rise persists in pregnancy until midgestation, and it falls thereafter to nonpregnant levels (69). The increase in body temperature is usually explained as a progesterone effect, the decline to the opposing effect of the more rapidly increasing estrogen concentrations during the second half of pregnancy (69). During pregnancy heat production increases progressively as a result of fetoplacental metabolism; heat loss may increase by vasodilatation in the skin, hyperventilation and sweat production. During exercise, body temperature will increase when heat production exceeds heat loss. Only 20 to 25% of the energy produced during exercise is used for power, while 75 to 80% is transformed into heat (9). Heat production depends on the intensity, duration, and efficiency of exercise and may increase 20-fold. Heat loss depends on the exchange area, on environmental factors, including ambient temperature and humidity, and on physiological adaptations such as vasodilatation and sweating. One study reported that the increase in rectal temperature during exercise declined progressively with advancing gestational age (34), but this may have been due to a concomittant progressive decline in exercise intensity. In another study in 4 women similar increases in skin and rectal temperature were observed during fairly strenuous exercise in pregnancy and in the postpartum period (74). This suggests that pregnant women are as equally well adapted as nonpregnant women to balance heat production and heat loss.

5.8 PHYSICAL TRAINING

The aim of physical training is to improve physical performance. Improvement of performance not only requires endurance training, but also the development of skills that are sport specific. To achieve a measurable result of endurance training it is necessary to expose the body to a relative overload of sufficient intensity, duration, and frequency (11). The maximal level of fitness is determined by individual factors including age, sex, and body composition. The increase in aerobic power that results from endurance training is accompanied by several physiological adaptations.

A very important cardiovascular adaptation that should occur in endurance training is an increase in maximal cardiac output, effected by increases in blood volume and stroke volume and not accompanied by a rise in maximal heart rate. Cardiac output at rest is unaffected by training because the heart rate decreases to compensate for the increase in stroke volume (11). In the absence of marked changes in blood pressure at rest and during exercise, the increase in cardiac output reflects a reduction in systemic vascular resistance as a result of training. The physiological adaptations to pregnancy resemble those of training in several respects. For example, cardiac output and blood volume increase while vascular resistance decreases. When training is superimposed on pregnancy, will the combined adaptations exceed those occurring in the single conditions?

Two studies have been published in which pregnant women were randomly assigned to a defined exercise program or to a control group that was not subjected to exercise (55,117). In the first study, training consisted of one hour of exercise three times a week at a heart rate of 140 beats-min^{-1} or more for a period of about 6 months (55). Physical working capacity was reported to increase by 14% in the training group of 31 women, but not in the 31 controls. However, this result should be interpreted with some care. Physical working capacity was reported as the square root of total work, while exercise time and power were not presented. When physical working capacity increased by 14% between 14 and 38 weeks' gestation as a result of training, it can be calculated from the data that this means that total work during the test actually increased by 30%. This could be due to increased fitness or to a prolonged test. In the second study (117) the training program consisted of aerobic activity at 60-80% of the measured maximal heart rate three times per week for one hour. Maximal oxygen uptake was reported to increase by 17% in the 10 women who trained from week 20 to 30 of gestation, compared with an 11% increase in the control group of 7 women. Unfortunately, the reported maximal values are in fact submaximal, as demonstrated by a mean maximal heart rate of 155-160 beats. min^{-1}. Also, the control group seems to be poorly matched for body weight and fitness level, as controls were 8 kg lighter and maximal oxygen uptake per kilogram of bodyweight was 6% lower.

Other studies in women participating in training programs during pregnancy

were uncontrolled (48) or potentially biased by nonrandom assignment of participants to the exercise and control groups (35,38). In a case report a woman performed endurance training (running) during a period of four years in which two pregnancies and lactation periods occurred (48). Maximal oxygen uptake was measured before and after the pregnancies, and estimated by extrapolation during gestation. Training after the first pregnancy resulted in a 25% increase in maximal oxygen uptake over a period of 8 months, after which it leveled off. Because of nausea and weakness she reduced the training in the first trimester of the next pregnancy resulting in a 17% decrease in estimated maximal oxygen uptake. When training was resumed, maximal oxygen uptake subsequently increased by 10% near term but it remained below the nonpregnant level. Maximal oxygen uptake seemed to be positively correlated with the weekly mileage of running, independent of pregnancy. In another study 12 healthy pregnant women participated in an aerobic exercise program for 25 minutes three times per week from 22 to 34 weeks' gestation at 65-70% predicted $\dot{V}O_2max$ (38). This resulted in an 18% increase in extrapolated maximal oxygen uptake whereas a 4% reduction was observed in 8 control women who did not exercise. Although it seems likely that training also has a positive effect on aerobic fitness in pregnancy, it is impossible to determine from the available data to what extent pregnancy affects the ability of women to improve aerobic fitness by physical training.

In a study of 18 women who exercised vigorously before pregnancy, efficiency, defined as the amount of oxygen used for a given amount of work, was reported to increase in early gestation. This early improvement in efficiency was noted to disappear more rapidly in a subgroup of women who discontinued exercise than in the women who continued their training (35). However, values of body weight and resting oxygen uptake were not presented in the report, although these variables are known to change during pregnancy and they would have had an effect on the calculation of the oxygen cost of exercise. Also, although the workload was presented as being constant, it must have increased because the treadmill speed was kept constant and body weight increases during pregnancy. Therefore, the conclusion that exercise efficiency is improved in early pregnancy is questionable. Although it may seem likely that efficiency is better maintained in women who continue their training during pregnancy than in women who become sedentary, more data are needed to support or refute such a conclusion.

5.9 **PSYCHOLOGICAL ASPECTS**

Pregnancy may cause psychological changes including usually mild, emotional and cognitive disturbances, with tendencies towards insomnia, anxiety, depression, and mood lability (71). Regular exercise is considered to improve mental well-being and self-esteem, and to reduce such feelings as depression

and anxiety (128). One would expect similar effects to occur in pregnant women. Indeed, positive psychological effects of regular exercise have been demonstrated in several studies in pregnant women (64,128,136). In a nonrandom study, 31 pregnant women who performed aerobic exercise for 20 minutes twice a week for 4 weeks during pregnancy scored lower on a physical discomfort checklist and higher on the Rosenberg self-esteem score than did the 22 non-exercising controls (128). In another study it was found that all 452 women who participated in a special exercise program for pregnant women had experienced some tension relief, improved self-image, and less common discomforts of pregnancy, when interviewed 6 weeks postpartum; women who continued to exercise until the end of pregnancy thought that the exercise was beneficial for labor and delivery (64). Such positive effects could obviously be biased by selection or be placebo effects. Pregnancy may also have a positive psychological effect resulting in better results from training. In an uncontrolled study in top female athletes, the investigator found that the women were psychologically more balanced and seemed to perform better after childbirth (139).

5.10 SAFETY ASPECTS AND GUIDELINES

It has been suggested that pregnancy increases the risk of trauma during sport activities (63). This finding was attributed to increased laxity or instability of posture and joints, perhaps mediated by the hormone relaxin (86). However, there appears to be little evidence to support such a suggestion. The center of gravity remains unchanged in the majority of pregnant women (70%) (68). Laxity has only been reported to be increased in pregnancy in the pubic joint (1), and in the fingers (25), and the impact of joint instability on the risk of trauma during exercise in pregnancy has not been studied.

Most studies on exercise training have focussed on pregnancy outcome. These studies were either uncontrolled or applied nonrandom assignment of participants to the exercise and control groups, and firm conclusions can not be drawn. However, as discussed in the previous chapters of this thesis, in the healthy mother with an uncomplicated pregnancy, the fetus does not seem to suffer hypoxic stress from maternal exercise.

Some authors using external tocodynamometry found that exercise might slightly increase uterine contractility (3,4,40,49,127), possibly through mechanical stimulation (49), whereas others did not (14,65,110,124). From the cumulative data and the results of the study reported in Chapter 3, it may be concluded that women during or after sport activities occasionally experience uterine contractions that subside when exercise is discontinued and do not progress into labor. However, further studies are needed to verify the safety of strenuous exercise in this respect.

One study based on interview data found that women who continued exercise training throughout pregnancy gained less weight and had shorter pregnan-

cies and babies with lower birthweights than those women who stopped exercising (31); surprisingly, this was found in women who exercised either strenuously or minimally. Several other studies have reported no major positive or negative effect of training or training status on pregnancy outcome (38,42, 56,64,72,78,106,137). No difference was found between the spontaneous abortion rate of about 15% in a small group of 90 vigorously exercising women and that in 29 controls, or that in the population at large (36). Although the available evidence suggests that rigorous exercise in healthy pregnant women is safe with regard to pregnancy outcome, further properly controlled studies are needed.

What guidelines should be given to the pregnant woman who wishes to participate in sport activities? Counselling should be based on a rational balance of possible advantages and disadvantages. Various potential benefits are suggested in the literature, such as maintenance or improvement of fitness and sleep, higher self-esteem, control of bodyweight, blood pressure, and glucose levels, improvement in appearance and posture, and a reduction in common complaints such as backache, varicose veins, and water retention (73,101). Reliable as many of these advantages may seem, there is, in fact, little scientific proof of their causal association with sport activities in pregnancy. For women professionally involved in exercise activities there may be an additional economic advantage. In considering the potential disadvantages and risks of sport activities, the following paragraphs do not aim for completeness but have been restricted to a discussion of some sport-specific aspects that may be relevant to healthy women with uncomplicated pregnancies.

Several characteristics of sport activities can be identified in relation to their potential risk in pregnant women. Some sports consist predominantly of dynamic, others of static exercise. Blood pressure increases to a much higher level during static than during dynamic exercise. Although no negative effects of strenuous static exercise were observed in a group of 15 pregnant women, despite a 50% increase in mean pressure (Lotgering, personal communication), too little is known about the safety of this type of exercise in pregnancy to recommend or discourage actively such sports as weight-lifting and windsurfing.

The level of exercise is determined by the intensity, duration, and frequency of the activities. As already discussed, uterine blood flow varies inversely with exercise intensity, but the compensatory mechanisms appear to be adequate, so that even exercise at maximal intensity does not harm the fetus. Exercise of long duration, relative to exercise intensity, carries the risk of lactate accumulation. The effect of maternal lactate accumulation on the fetus has not been well established. Frequency of exercise is not a useful discriminator per se but must be related to the intensity and the duration. Exhaustive endurance exercises like marathon and triathlon cannot be recommended, but most less demanding sport activities are probably safe.

Although exercise in itself may be harmless, some sports are less advisable because of the associated risk of trauma. Even though it has not been reported

in the literature, one might speculate that in pregnancies advanced beyond the first trimester direct abdominal trauma in contact sports such as basketball, soccer, and karate could jeopardize the fetus, possibly through placental abruption. Likewise, direct abdominal trauma could also result from accidents that may occur in such sports like downhill skiing, skating and horseback riding. Water may accidently and forcibly enter the cervix in a waterski accident (79). Sport accidents may be harmful to the fetus also without direct uterine involvement when they cause major trauma, circulatory collaps, or shock. It has been suggested that pregnancy predisposes to injury in sports that involve rapid turning and twisting such as racket sports, and this has been attributed to a greater laxity of the joints and altered balance (33,37,98). However, sport injuries during pregnancy are anecdotal and the risks have not been studied systematically.

The environment in which a sport is performed may in itself be a risk factor by affecting body temperature. It has been suggested that hyperthermia could be teratogenic (116), but a direct relationship between exercise-induced hyperthermia and congenital abnormalities has not been demonstrated (84). Hypothermia may occur, for example in mountain sports. Obviously, the choice of clothing should be such that extreme hypo- and hyperthermia is avoided during exercise, also in pregnancy. There is no evidence that low barometric pressure in high-altitude sports like mountain climbing and skiing has any important effect on maternal oxygenation and blood pressure, or on fetal heart rate during mild exercise at altitudes of up to 2500 metres (14). Exercise of greater strain or at higher altitude has not been studied in pregnant women, nor has the factor of acclimatization. The effect of high barometric pressure has been studied in a group of 208 pregnant scuba diving women (20). Congenital anomalies were observed in 3 out of 24 pregnant women who reported dives to a depth of 100 feet or more during the first trimester. The authors suggest that this represented an increased incidence of congenital anomalies associated with first trimester deep sea diving; they recommend limiting dives to a depth of 60 feet and to a duration of half the limits of the US Navy decompression tables (20). However, a much larger group of women will be needed to determine if scuba-diving is indeed teratogenic and if these arbitrary recommendations are safe.

General recommendations are necessarily conservative, as demonstrated by the guidelines of the American College of Obstetricians and Gynecologists for exercise during pregnancy and postpartum (2) shown in Table 5.5. However, some of these recommendations seem to lack a physiological basis. For example, why should competitive activities always be discouraged, heart rate not exceed 140 beats per minute, strenuous activity not exceed 15 minutes or core temperature not exceed 38°C? And what proof is there that connective tissue laxity is increased throughout pregnancy and thereby increases the risk of joint injury and instability so that muscles stretching and joint movements should be limited? Individual factors heavily affect the balance of advantages and disadvantages of exercise in pregnancy. Therefore, counselling should be on an individual basis rather than by general guidelines.

Table 5.5. American College of Obstetricians and Gynecologists. Guidelines for Exercise during Pregnancy and Postpartum.

Pregnancy and postpartum

1. Regular exercise (at least three times per week) is preferable to intermittent activity. Competitive activities should be discouraged.
2. Vigorous exercise should not be performed in hot, humid weather or during a period of febrile illness.
3. Ballistic movements (jerky, bouncy motions) should be avoided. Exercise should be done on a wooden floor or a tightly carpeted surface to reduce shock and provide sure footing.
4. Deep flexion or extension of joints should be avoided because of connective tissue laxity. Activities that require jumping, jarring motions or rapid changes in direction should be avoided because of joint instability.
5. Vigorous exercise should be preceded by a five-minute period of muscle warm-up. This can be accomplished by slow walking or stationary cycling with low resistance.
6. Vigorous exercise should be followed by a period of gradually declining activity that induces gentle stationary stretching. Because connective tissue laxity increases the risk of joint injury, stretches should not be taken to the point of maximum resistance.
7. Heart rate should be measured at times of peak activity. Target heart rates established in consultation with the physician should not be exceeded.
8. Care should be taken to gradually rise from the floor to avoid orthostatic hypotension. Some form of activity involving the legs should be continued for a brief period.
9. Liquids should be taken liberally before and after exercise to prevent dehydration. If necessary, activity should be interrupted to replenish fluids.
10. Women who have led sedentary lifestyles should begin with physical activity of very low intensity and advance activity levels very gradually.
11. Activity should be stopped and the physician consulted if any unusual symptoms appear.

Pregnancy only

1. Maternal heart rate should not exceed 140 beats per minute.
2. Strenuous activities should not exceed 15 minutes in duration.
3. No exercise should be performed in the supine position after the fourth month of gestation is completed.
4. Exercises that employ the Valsalva maneuver should be avoided.
5. Caloric intake should be adequate to meet not only the extra needs of pregnancy, but also of the exercise performed.
6. Maternal core temperature should not exceed 38°C (100.4°F).

From American College of Obstetricians and Gynecologists. Exercise during pregnancy and the postnatal period. Home exercise programs. Washington D.C.: American College of Obstetricians and Gynecologists, 1985:4. (2)

SUMMARY

This thesis consists of five chapters dealing with various aspects of physiological responses to strenuous dynamic exercise in pregnant women.

CHAPTER ONE is a brief introduction, describing the background and the objectives of the investigations presented in this thesis.

CHAPTER TWO deals with the question whether or not pregnancy affects the ability to perform dynamic exercise. The study reported in this chapter was performed in 33 healthy women with an uncomplicated pregnancy and delivery. Power, heart rate, oxygen uptake, carbon dioxide output, and ventilation were determined at rest and during maximal bicycle and treadmill exercise tests with rapidly increasing exercise intensities at 16, 25, and 35 weeks' gestation, and 7 weeks after delivery. Maximal heart rate was about 2% lower throughout pregnancy compared with the nonpregnant state. Maximal oxygen uptake was not affected by pregnancy during bicycle and treadmill exercise. As a result of increased oxygen uptake at rest, the amount of oxygen available for exercise (exercise minus rest) tended to decrease with advancing gestation, reaching statistical significance only during treadmill exercise at 35 weeks' gestation. Power showed a positive linear correlation with oxygen availability during exercise, and the relationship was not affected by pregnancy. Carbon dioxide output at maximal exercise was lower during pregnancy than at 7 weeks postpartum, whereas maximal ventilation was found to be increased during gestation. Except for the hyperventilation of pregnancy, which was maintained at maximal aerobic exercise, the relationship between ventilation and carbon dioxide output (or oxygen uptake) was not affected by gestation.
It is concluded that pregnancy does not have a marked effect on maximal aerobic power.

CHAPTER THREE presents a study of maternal and fetal cardiovascular responses to strenuous bicycle exercise during pregnancy and the postpartum period. The investigations were done in the same group of 33 women described in Chapter 2, in the same periods of gestation and postpartum. Variables were selected with relevance to safety: the maternal electrocardiogram and blood pressure, uterine contractility, and fetal heart rate. The exercise electrocardiogram demonstrated depression of the ST-segment in 12% of the 33 women in the absence of clinical signs of ischemia; the incidence of these changes was unaffected by pregnancy. This supports earlier suggestions that exercise electrocardiography is of limited value in healthy pregnant or nonpregnant women for the detection of ischemia. Blood pressures at rest were slightly lower

during the first and second trimester than in the third trimester of pregnancy, and postpartum. However, the blood pressure response to exercise at approximately 75% $\dot{V}O_2$max was not influenced by pregnancy.

The fetal heart rate could not be recorded reliably during maternal exercise. After a maximal bicycle test, fetal heart rate was slightly elevated (4 beats per minute) compared with control values at rest, probably as a result of increased body temperature; the heart rate pattern was unaltered. Uterine contractility after exercise was slightly increased in some women, but without progression into labor.

These findings support the view that even strenuous exercise during pregnancy is not harmful to the healthy mother and fetus.

CHAPTER FOUR describes an attempt to determine the accuracy of estimated values of maximal heart rate and oxygen uptake during pregnancy and after delivery, using the data reported in Chapter 2.

Estimated maximal heart rate overestimated measured heart rate (220 - age in years) by 8% during bicycle and 5% during treadmill exercise. Maximal oxygen uptake estimated with the use of Åstrands nomogram overestimated measured maximal oxygen uptake markedly (20%) during bicycle exercise, but not during treadmill exercise. Variation in individual errors was large. Because the mean error decreased with advancing gestational age, application of this method gave an erroneous impression of a reduction in maximal oxygen uptake during bicycle exercise in pregnancy. When maximal oxygen uptake was estimated differently, by extrapolation of submaximal values of heart rate and oxygen uptake to estimated maximal heart rate, values were not significantly different from measured maximal oxygen uptake, but variation in individual errors was large. The apparently good average outcome of these estimated values results from two opposing errors: 1. estimated maximal heart rate overestimates measured maximal heart rate and thereby estimated maximal oxygen uptake, 2. the relationship between heart rate and percent $\dot{V}O_2$max is bilinear rather than linear and this results in an underestimate of maximal oxygen uptake.

On the basis of this study it is recommended that, for research purposes, maximal heart rate and maximal oxygen uptake in pregnant and postpartum women be measured rather than estimated.

CHAPTER FIVE reviews known data about the physiological adaptations to exercise stress superimposed upon the changes of pregnancy in humans, and explores what is not known.

Oxygen uptake at rest increases in a linear fashion with advancing gestational age whereas maximal oxygen uptake is unaffected by pregnancy. Oxygen uptake during submaximal exercise in pregnancy is markedly influenced by oxygen uptake at rest and exercise intensity.

Cardiac output increases during pregnancy due to a rise in both heart rate and stroke volume. The exercise-induced increase in cardiac output is virtually similar in pregnant and nonpregnant women, so that exercise values in pregnant women are higher. Pregnancy has no marked effect on the blood pressure response to dynamic exercise.

The hyperventilation of pregnancy persists during exercise. Carbon dioxide output at rest increases with gestational age and the increase is slightly larger than the increase in oxygen uptake. This results in a small rise in the respiratory exchange ratio, which reflects the predominant use of carbohydrates by the fetal placental unit. Maximal carbon dioxide output decreases gradually with gestational age, while maximal oxygen uptake remains unaltered. Therefore, the respiratory exchange ratio during maximal exercise is lower in pregnancy than in the postpartum period. The mechanisms and implications of this finding remain to be determined.

The effect of exercise on carbohydrate and fat metabolism in pregnancy has not been studied in detail and the results of the available studies are inconclusive. The same applies to the endocrine effects of exercise in pregnancy.

Despite greater heat production in pregnancy, pregnant women seem equally well adapted to balance heat production and heat loss during exercise as are nonpregnant women.

Few randomized controlled studies on physical training have been performed during pregnancy and it is impossible to determine from these reports to what extent pregnancy affects the ability of women to improve their aerobic fitness by physical training. Positive psychological effects of regular exercise have been reported in several studies of pregnant women.

Safety aspects and guidelines on exercise in pregnancy presented in the literature should be considered with care as they are based on personal opinion rather than on controlled observations. General recommendations must necessarily be conservative whereas individual factors may heavily affect the balance of possible advantages and disadvantages of exercise in pregnancy. Therefore, counseling should be on an individual basis rather than by general guidelines.

SAMENVATTING

Dit proefschrift bestaat uit 5 hoofdstukken waarin verschillende aspecten worden behandeld van de fysiologische aanpassing van zwangere vrouwen aan zware lichamelijke inspanning.

HOOFDSTUK EEN geeft een korte inleiding, waarin de achtergronden en doelstellingen worden beschreven van de in dit proefschrift gepresenteerde onderzoeken.

HOOFDSTUK TWEE handelt over de vraag of zwangerschap de mogelijkheid tot het verrichten van dynamische inspanning beïnvloedt. Het hier beschreven onderzoek werd uitgevoerd bij 33 gezonde vrouwen met een ongecompliceerde zwangerschap en bevalling. In rust en tijdens maximale inspanningstesten op de fiets en op de tredmolen werden vermogen, hartfrequentie, zuurstofopname, koolzuurafgifte en ventilatie bepaald. Daarbij werd gebruik gemaakt van een snel progressief inspanningsprotocol. De testen werden uitgevoerd in de 16e, 25e en 35e week van de zwangerschap en 7 weken na de bevalling. Tijdens de zwangerschap was de maximale hartfrequentie ongeveer 2% lager dan buiten de zwangerschap. De maximale zuurstofopname tijdens inspanning, zowel op de fiets als op de tredmolen, veranderde niet in de zwangerschap. Tengevolge van de toegenomen zuurstofopname in rust vertoonde de hoeveelheid zuurstof beschikbaar voor inspanning (inspanning minus rust) de neiging te dalen in de loop van de zwangerschap. Deze daling was echter alleen in de 35e week van de zwangerschap tijdens inspanning op de tredmolen statistisch significant. Het vermogen vertoonde een positieve lineaire correlatie met de beschikbaarheid van zuurstof tijdens de inspanning; zwangerschap had geen effect op deze relatie. De koolzuurafgifte bij maximale inspanning was lager tijdens de zwangerschap dan 7 weken postpartum, terwijl de maximale ventilatie verhoogd was tijdens de zwangerschap. Behalve de in de zwangerschap bestaande hyperventilatie, die ook tijdens maximale aerobe inspanning gehandhaafd bleef, veranderde de relatie tussen ventilatie en koolzuurafgifte (of zuurstofopname) niet als gevolg van de zwangerschap.

De conclusie is, dat zwangerschap geen duidelijk effect heeft op het maximale aerobe vermogen.

HOOFDSTUK DRIE omvat een onderzoek naar de moederlijke en foetale cardiovasculaire aanpassingen aan zware inspanning op de fiets, tijdens de zwangerschap en in de postpartum periode. Het onderzoek vond plaats bij dezelfde 33 vrouwen als beschreven in hoofdstuk 2, in dezelfde periodes van de zwangerschap en na de bevalling. In het bijzonder werden variabelen bestudeerd die relevant werden geacht met betrekking tot de veiligheid van

moeder en foetus, te weten: het moederlijke electrocardiogram en de moederlijke bloeddruk, de contractiliteit van de uterus en de foetale hartfrequentie. Het inspannings-electrocardiogram vertoonde een daling van het ST-segment bij 12% van de 33 vrouwen, zonder dat er klinische aanwijzingen bestonden voor ischaemie; de incidentie van deze veranderingen werd niet beïnvloed door de zwangerschap. Dit ondersteunt eerdere aanwijzingen, dat het inspannings-electrocardiogram bij gezonde zwangere of niet-zwangere vrouwen van beperkte waarde is voor het aantonen van ischaemie. De bloeddrukwaarden in rust waren in het eerste en tweede trimester iets lager dan in het derde trimester en na de bevalling. De bloeddrukrespons op een inspanning van ongeveer 75% van de maximale zuurstofopname werd niet door de zwangerschap beïnvloed.

De foetale hartfrequentie kon tijdens moederlijke inspanning niet betrouwbaar worden gemeten. Na een maximale fietsproef bleek de foetale hartfrequentie vergeleken met de controlewaarden iets te zijn verhoogd (4 slagen per minuut), waarschijnlijk als gevolg van een verhoogde lichaamstemperatuur; het patroon van de foetale hartfrequentie was onveranderd. Na inspanning was de contractiliteit van de uterus licht verhoogd, echter zonder dat echte weeën ontstonden.

Deze bevindingen ondersteunen de opvatting, dat zelfs zware inspanning tijdens de zwangerschap niet schadelijk is voor de gezonde moeder en foetus.

HOOFDSTUK VIER beschrijft een poging om de nauwkeurigheid te bepalen van geschatte waarden van de maximale hartfrequentie en zuurstofopname tijdens de zwangerschap en na de bevalling, waarbij gebruik werd gemaakt van de in hoofdstuk 2 vermelde data.

De geschatte maximale hartfrequentie (220 - leeftijd in jaren) overschatte de gemeten hartfrequentie met 8% tijdens fietsinspanning en met 5% tijdens inspanning op de tredmolen. De zuurstofopname geschat met behulp van het Åstrand nomogram overschatte de gemeten maximale zuurstofopname aanzienlijk (20%) tijdens de fietsproeven, maar niet tijdens de loopproeven. De variatie in de individuele fouten was groot. Omdat de gemiddelde fout afnam in de loop van de zwangerschap, wekte toepassing van deze methode ten onrechte de indruk dat de maximale zuurstofopname tijdens inspanning op de fiets afneemt in de loop van de zwangerschap. Wanneer de maximale zuurstofopname op een andere wijze werd geschat, door extrapolatie van submaximale waarden van hartfrequentie en zuurstofopname tot de geschatte maximale hartfrequentie, dan waren deze waarden niet significant verschillend van de gemeten maximale zuurstofopname, maar wel was de variatie in de individuele fouten groot. De ogenschijnlijk goede gemiddelde uitkomst van deze geschatte waarden wordt veroorzaakt door twee tegenovergestelde fouten: 1. de geschatte maximale hartfrequentie overschat de gemeten maximale hartfrequentie en daarmee ook de geschatte maximale zuurstofopname, 2. de relatie tussen de hartfrequentie en het percentage $\dot{V}O_2max$ is eerder bilineair

dan lineair en dit resulteert in een onderschatting van de maximale zuurstofopname.

Op grond van de resultaten van dit onderzoek wordt aangeraden om, voor onderzoeksdoeleinden, de maximale hartfrequentie en de maximale zuurstofopname bij zwangere en niet-zwangere vrouwen te meten in plaats van te schatten.

HOOFDSTUK VIJF geeft een overzicht van wat er bekend en niet bekend is over de fysiologische aanpassingen van de zwangere vrouw wanneer zij wordt blootgesteld aan de stress van inspanning bovenop de fysiologische veranderingen van de zwangerschap.

De zuurstofopname in rust vertoont een lineaire stijging in de loop van de zwangerschap, terwijl de maximale zuurstofopname niet verandert. De zuurstofopname tijdens submaximale inspanning in de zwangerschap wordt in belangrijke mate beïnvloed door de zuurstofopname in rust en door de inspanningsintensiteit.

Het hartminuutvolume neemt in de zwangerschap toe als gevolg van een stijging van de hartfrequentie en het slagvolume. De door inspanning geïnduceerde toename van het hartminuutvolume is bij zwangere en niet-zwangere vrouwen vrijwel gelijk, zodat de inspanningswaarden bij zwangeren hoger uitkomen. Zwangerschap heeft geen duidelijk effect op de bloeddrukverandering als gevolg van dynamische inspanning.

De in de zwangerschap fysiologisch optredende hyperventilatie blijft gehandhaafd tijdens inspanning. De koolzuurafgifte in rust stijgt in de loop van de zwangerschap en deze toename is iets groter dan de stijging van de zuurstofopname. Dit resulteert in een kleine stijging van de respiratoire uitwisselings verhouding, hetgeen waarschijnlijk het overwegend gebruik van koolhydraten door de foetoplacentaire eenheid weerspiegelt. De maximale koolzuurafgifte daalt geleidelijk bij een toename van de zwangerschapduur, terwijl de maximale zuurstofopname onveranderd blijft. Daarom is de respiratoire uitwisselings verhouding tijdens maximale inspanning in de zwangerschap lager dan in de postpartum periode. De mechanismen en gevolgen van deze bevinding moeten nog nader worden onderzocht.

Het effect van inspanning tijdens de zwangerschap op de koolhydraat- en vetstofwisseling is nog niet tot in detail bestudeerd en de resultaten van de tot op heden beschikbare onderzoeken zijn niet duidelijk. Voor het effect van inspanning tijdens de zwangerschap op het endocriene systeem geldt hetzelfde.

Ondanks een grotere warmteproduktie in de zwangerschap, lijken zwangere vrouwen even goed als niet-zwangeren in staat te zijn het evenwicht tussen warmteproduktie en warmteverlies te handhaven.

Op het gebied van fysieke training tijdens de zwangerschap zijn maar weinig gecontroleerde en gerandomiseerde onderzoeken uitgevoerd. Het is daarom onmogelijk om op grond van gepubliceerd onderzoek te bepalen of, en zo

ja in welke mate, zwangerschap de mogelijkheid beïnvloedt om de aerobe fitheid door middel van fysieke training te verbeteren. Positieve psychologische effecten van regelmatige lichamelijke inspanning door zwangeren worden door verschillende auteurs genoemd.

De veiligheidsaspecten en richtlijnen voor inspanning in de zwangerschap die in de literatuur naar voren worden gebracht dienen kritisch te worden bekeken, aangezien zij meer gebaseerd zijn op persoonlijke opvattingen dan op gecontroleerde waarnemingen. Algemene aanbevelingen moeten noodzakelijkerwijs behoudend zijn, terwijl individuele factoren de balans tussen voor- en nadelen van inspanning tijdens de zwangerschap in belangrijke mate kunnen beïnvloeden. Daarom dient het geven van advies meer gebaseerd te zijn op individuele factoren dan op algemene richtlijnen.

GLOSSARY

Aerobic: Having molecular oxygen present; describes metabolic process utilizing oxygen.+

Anaerobic: Lacking or inadequate molecular oxygen; describes any metabolic process that does not use molecular oxygen.+

Carbon dioxide output ($\dot{V}CO_2$): The amount of carbon dioxide (CO_2) exhaled from the body into the atmosphere per unit time, expressed in ml/min or liter/min.+

Cardiac output: The flow of blood from the heart in a particular period of time, usually expressed in liter per minute.+

Cardiotocography: Antepartum recording of the fetal heart rate, and of uterine contractility.

Efficiency: Work relative to oxygen uptake (exercise minus rest) during the period of time in which the work was performed, expressed in kiloJoule per liter O_2.

Endurance: The time limit of a person's ability to maintain either a specific isometric force or a specific power level involving combinations of concentric or eccentric muscular contractions.*

Energy: The capability of producing force, performing work, or generating heat, expressed in Joule or kiloJoule.*

Exercise: Any and all activity involving generation of force by activated muscle(s) which results in a disruption of a homeostatic state. In dynamic exercise, the muscle may perform shortening (concentric) contractions or be overcome by external resistance and perform lengthening (eccentric) contractions. When muscle force does not result in movement, the contraction is called static or isometric.*

Exercise intensity: A specific level of maintenance of muscular activity that can be quantified in terms of power (energy expenditure or work performed per unit of time), isometric force sustained, velocity of progression, or percentage of maximal oxygen uptake.*

Fischer score: Scoring system for antepartum cardiotocograms based on five criteria: basal fetal heart rate, bandwidth, zero-crossings, accelerations and decelerations. Zero to two points are assigned to every variable; fetal condition is considered good when the score is between 8 and 10; questionable between 5 and 7 and poor when it is below 5.

Force: That which changes or tends to change the state of rest or motion in matter, expressed in Newton.*

Gas exchange ratio (R): The ratio of the carbon dioxide output to the oxygen uptake per unit time.+

Incremental exercise test: An exercise test designed to provide progressive stress to the subject. The work rate is usually increased over uniform periods of time.+

Maximal oxygen uptake ($\dot{V}O_2max$): The highest oxygen uptake obtainable for a given form of exercise despite further work rate increases and effort by the subject.+

Oxygen uptake ($\dot{V}O_2$): The amount of oxygen extracted from the inspired gas in a given period of time, expressed in ml/min or liter/min.+

Physical activity index: Index, calculated as the 24-hour average metabolic constant from recorded daily activities and the metabolic constant values assigned to these activities minus 1.0 to correct for basal metabolism.

Power: The rate of performing work; the derivative of work with respect to time; the product of force and velocity, expressed in watt.*

Speed: Total distance travelled per unit of time, expressed in meter per second.*

Stroke volume: The volume of blood ejected from either ventricle of the heart at a single beat.+

Velocity: Displacement per unit of time. A vector quantity requiring that direction be stated or strongly implied, expressed in meter per second or kilometer per hour.*

Work: Force expressed through a distance but with no limitation on time, expressed in Joule or kiloJoule).*

+ Modified after Glossary by Wasserman et al. (131).

* Modified after Information for authors, Medicine and Science in Sports and Exercise, 1989.

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Examine from the head to toes
Before you dare to diagnose
More harm is done because you do not look
Than from not knowing what is in the book

(Zeta)