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Review

Thermoregulation and Endocrine Response During Exercise in Pregnancy

Manuela Filipec [1,*] and Marinela Jadanec Đurin [2]

[1] Department of Physiotherapy, University North, 42000 Varaždin, Croatia
[2] Department for Physical Medicine and Rehabilitation, Clinical Hospital Sveti Duh, 10000 Zagreb, Croatia; marinela.jadanec@gmail.com
* Correspondence: mfilipec@unin.hr

Abstract: Pregnancy is followed by complex and intense physiological changes in the maternal body, whose goal is to provide all the needs of the mother and the growing fetus. The endocrine system and thermoregulation integrate physiologic responses and play an important role in maintaining homeostatic conditions during exercise in pregnancy. Changes and adaptations during exercise in pregnancy are conditioned by the influence of numerous metabolic and biochemical events, which act on the target tissues through physiological mechanisms. Many hormones are released during exercise and a variety of cells are responsible for a number of different responses. Pregnancy involves changes in thermoregulation that lead to an increase in heat production and its preservation. Physiological mechanisms that enable the release of excess body temperature in order for the body to maintain an ideal temperature during exercise are increased, such as sweating and vasodilation of blood vessels. The reaction of a mother to exercise training depends on the exercise duration and intensity of training, the nutrient profile, and the level of fitness. Exercise has many improving effects on functional aspects of tissues and organs, resulting in improved health and/or performance.

Keywords: thermoregulation; endocrine response; exercise; pregnancy

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1. Introduction

During exercise in pregnancy, numerous adaptations of the body's systems occur, of which the endocrine and thermoregulatory systems are discussed in this paper. Also, regular exercise leads to numerous adaptive physiological changes, especially in the cardiorespiratory system and metabolic changes by which the pregnant woman's body adapts (Table 1) to the repeated demands to ensure oxygen and substrate for energy needs in metabolically active tissues [1,2]. The severity of the adjustments is connected with the amount of fitness of the pregnant woman and the intensity, duration, and frequency of exercise.

The endocrine system regulates, connects, and coordinates various physiological processes and thus ensures the long-term homeostasis of the organism [3–5]. At the same time, together with the nervous system, it supervises the regulation of all functions in the body. Through mutual interaction, these systems connect individual parts of the organism into a functional whole. The impact of the nervous system on the endocrine system can be direct (it affects directly a certain gland) or indirect (it affects certain glands via the pituitary gland, the main gland of the endocrine system) [5–10]. On the other hand, the function of the nervous system is significantly influenced by the products of the endocrine system [6,7]. The endocrine and nervous systems are responsible for regulating the speed

of chemical processes, the transport of substances, the relationship between water and electrolytes, growth, development, and numerous other physiological processes [8–12]. Therefore, it can be said that the work of the two main control systems is interdependent, and their coordinated function is necessary for physiological processes during exercise [13]. The endocrine system, as a system of glands with internal secretion, secretes its products (hormones) directly into the bloodstream, thus regulating numerous metabolic processes, especially during exercise [14–17]. Lipid metabolism is the initial source of energy at low exercise intensities (<40% VO_2 max) [4]. By increasing the intensity of exercise, circulating glucose metabolism is enhanced, and in pregnancy, the concentration of glucose in the circulation can drop up to 31% [4]. But, compared to nonpregnant women, insulin remains elevated in pregnant women during exercise. This can carry on, encouraging the transfer of glucose to the fetus [4,13,15]. The perception of improved glucose clearance and reduced hyperinsulinemia with exercise appears to be a mechanism by which the risk of developing gestational diabetes can be reduced [4,14]. Also, exercise performed during pregnancy reduces the risk of gestational diabetes-related complications, notably macrosomia [5,13,15].

Table 1. Physiological adjustments during pregnancy [4,7,9].

Parameter	Change in Early Pregnancy/First Trimester	Change in Third Trimester	Comment
Plasma volume	Increase by 6% in first trimester	Increase by 48% in third trimester	Increase as the pregnancy progresses
Red cell volume	Decreases	Decreases as the pregnancy progresses	As a result of the relatively much greater increase in plasma volume, red cells in the blood are “diluted”.
Colloid osmotic pressure	25.5 mmHg before pregnancy	Decrease of 22 to 23 mmHg in third trimester	Contributes to edema of lower extremities and weight gain in the third trimester.
Cardiac output (CO)	Increases by 40% at the end of the second trimester	Remains stable, peak CO = 6.1–6.3 L/min	Increase in heart rate by 5–10% and stroke volume by 10–20%; blood pressure is stable until the second trimester and then decreases by 5–10% until the third trimester. Then, the blood pressure returns to the values of the first trimester. In the third trimester, CO depends on the position of the pregnant woman. The supinated position leads to the compression of the uterus on the large blood vessels, and there is a reduction in CO by 25–30%; symptomatic hypotension will appear in 10% of pregnant women.
Renal blood flow (RBF) and glomerular filtration rate (GFR)	Increase by 40% RBF/GFR from 6 weeks	Increase by 50% RBF/GFR to the middle of the third trimester	Urinary output is minimally reduced. There is often a trace of 1+ glycosuria, a decrease of 20–40% of serum uric acid, creatine, and urea in the blood.
Respiratory volume	Increase by 35%	Increase by 50%	Helps to explain the increase in minute ventilation.
Total lung capacity	Unchanged or slightly decreased	Slightly decreased	Elevation of the diaphragm due to the enlargement of the uterus.
Minute ventilation	Increase by 48% in first trimester	Maintain its level as the pregnancy progresses	Decrease in arterial PCO_2 to 33 mmHg; arterial pH increases to 7.44; arterial pH maintained by increased renal bicarbonate excretion (normal serum bicarbonate: 20 mEq/L).
Oxygen consumption		Increase by 10–20%	Under the influence of body weight gain during pregnancy and fetoplacental oxygen consumption.

Table 1. *Cont.*

Parameter	Change in Early Pregnancy/First Trimester	Change in Third Trimester	Comment
Glucose metabolism	Basal endogenous glucose production increase	Constant throughout pregnancy	Fetal glucose consumption is 2–10 mg/kg/min, rapid drop in blood glucose in pregnant women during exercise, decrease in insulin sensitivity due to increase in cortisol, human placental lactogen, and proinflammatory cytokines.
Lipid metabolism	Increased fat storage in first trimester ("anabolic state")	Katabolic state in third trimester	Increase in insulin, human placental lactogen, and proinflammatory cytokines, earlier ketonemia, ketonuria.

Hormones control and coordinate the chemical processes of their target cells and influence them. The entire activity of the glands is regulated by the hypothalamus, the part of the brain responsible for coordinating the work of the nervous and endocrine systems [18].

The hormonal changes that appear during pregnancy, regulated in part by the corpus luteum at the beginning of pregnancy, and later on by the fetoplacental unit and maternal endocrine glands, are accountable for numerous changes in body systems during exercise like respiratory and cardiovascular [7,15]. Hormonal changes and respiratory responses to exercise appear to contribute to pregnant women's perception that they have to exert more effort during exercise [7,13]. It is thought that increased ventilation and effort of the respiratory muscles influence the pregnancy-induced increase in shortness of breath during exertion. Respiratory discomfort close to tolerance limits in late pregnancy is contributed by dynamic mechanical ventilation limitations [7,14].

It seems that during non-weight-bearing exercise, the difference in absolute VO_2 (L/min) between pregnant and nonpregnant women is unaltered or enhanced during pregnancy. On the contrary, during weight-bearing exercise, absolute VO_2 (L/min) is further enhanced and is considered to be related to gestational weight gain [4,7,9]. Also, it is believed that the factor that contributes to the raised sense of dyspnea (breathlessness) can be the enhancement of ventilation during exercise. Reduced heart rate reserve in pregnancy means that the increase in heart rate for a certain increase in VO_2 is lower during pregnancy, especially at intensities below 70% of heart rate reserve [4,7,9]. For example, during pregnancy, stroke volume at rest is enhanced until the second trimester before it decreases (but does not approach) pre-pregnancy levels during childbirth [2,4,7]. This early increase in stroke volume appears along with a progressive increase in volume during pregnancy. Therefore, changes in stroke volume may be partially attributable to Frank–Starling mechanisms (e.g., increased preload). Together with increased heart rate, this contributes to a higher cardiac output in pregnant women [4,13].

It is important to keep in mind thermoregulatory adjustments during exercise in pregnancy and their impact on the pregnant woman and the fetus. The normal core temperature during exercise depends on environmental conditions, the state of training and acclimatization, the intensity and duration of exercise, the degree of hydration of the pregnant woman, and individual differences [17,18]. In response to heat stress, there is a redistribution of blood from the core of the body to the outer envelope. It is lost from the body by radiation, conduction, convection, and evaporation of water in the respiratory tract and on the skin [17]. Evaporation is considered to be the main physiological pathway through which heat is released and prevents overheating during exercise or high ambient temperatures. However, the fetus is dependent on the mother for the loss of heat it produces [13,17]. A reversed feto–maternal temperature gradient (where heat flows from mother to fetus rather than in the reverse direction) can occur if the production in the

mother is high, and the dissipation of heat from the mother is slow (i.e., she exercises in a warm and humid environment) [9,17].

Temperature enhances proportional to exercise intensity, while relative workload determines the change in core temperature during exercise. The heat loss will gradually correspond to the heat gain, and a thermal equilibrium state can be reached at a raised core temperature if the exercise intensity is not too high, and the ambient conditions are not too difficult [17]. Thus, the core temperature should not elevate more than 1.5 °C compared to the resting state or over 38.9 °C during pregnancy [17]. Data on temperature regulation during pregnancy show that exposure to hyperthermia can be dangerous for the fetus [17,18]. Teratogenic effects may appear in early pregnancy, while uteroplacental insufficiency is possible in late pregnancy [18]. During pregnancy, both mother and fetus should tolerate the stress of exercise well so that the mother benefits, and the fetus is protected.

The aim of this review is to present thermoregulatory and endocrine responses during exercise in pregnancy. Knowledge of the adaptations of the thermoregulatory and endocrine systems during exercise in pregnancy is necessary for creating and modifying an exercise program.

2. Endocrine Response During Exercise

The main endocrine glands in the context of exercise include: the pituitary gland, thyroid gland, parathyroid gland, adrenal glands, and pancreas. The pituitary gland is the leading gland because its hormones regulate other important endocrine glands in the body (including the adrenal, thyroid, and reproductive glands) and, in some cases, have straight regulatory effects on major tissues, such as those of the musculoskeletal system [19]. From the aspect of exercise, the most important hormones of the adenohypophysis are growth hormone, adenocorticotropic hormone, thyrotropin hormone, and antidiuretic hormone of the neurohypophysis [20].

Growth hormone (somatotropic hormone) acts directly on bones and muscles, stimulates protein synthesis and the growth of all cells and tissues, and affects the metabolism of carbohydrates and lipids. It participates in metabolism by stimulating the uptake of amino acids and their incorporation into proteins [21]. Also, it participates in the metabolism and mobilization of lipids and glucose from liver glycogen and pyruvate and modifies the gluconeogenic effect of corticosteroids. An enhancement in the concentration of growth hormone in the blood activates the release of insulin-like growth factors (IGFs) from the liver and other tissues, which are the chief drivers of autocrine and paracrine mechanisms of muscle hypertrophy [21–23]. Adenocorticotropic hormone stimulates the synthesis and secretion of adrenal cortex hormones (aldosterone and cortisol) and affects the metabolism of water and electrolytes in the liver [24]. Thyrotropin hormone stimulates the synthesis and secretion of thyroid hormones (thyroxine and triiodothyronine), increases the use of oxygen and protein synthesis, and affects the metabolism of carbohydrates and lipids [25]. Antidiuretic hormone (vasopressin) plays an important role in regulating the concentration of body fluids. Under its influence, the excretion of water through the kidneys decreases due to the increased reabsorption of water in the renal tubules. It also has an effect on the central nervous system, which enables better concentration and attention, greater operational reliability, and better coordination of movements [26].

The thyroid gland produces hormones that have a significant role in regulating the body's overall metabolism. Thyroxine and triiodothyronine increase the metabolic activity of almost all tissues in the body. Their specific physiological mechanism is manifested in basal metabolism, carbohydrate and lipid metabolism, and protein synthesis [27]. They also affect the work of the cardiovascular, respiratory, digestive, nervous, and locomotor systems. It enhances the stimulating effects of other hormones on the absorption of glucose from the

digestive system, lipolysis, and proteolysis. With an increased level of thyroxine, increased oxygen consumption, carbon dioxide formation, which increases the frequency and depth of breathing, and increased body heat generation are noticeable [27,28]. Thyroxine also increases cardiac output, which ensures sufficient tissue supply with oxygen. It stimulates the mitochondria, which, through increased oxidation, burn larger amounts of fatty acids as energy, which results in a large consumption of calories and a rapid reduction in fat deposits. In other words, it significantly accelerates the metabolism in the body [29]. Calcitonin regulates the concentration of calcium in the extracellular fluid and promotes its deposition in the bones.

The parathyroid gland secretes parathyroid hormone (parathormone), which regulates the concentration of calcium and phosphate in the extracellular fluid by affecting their absorption from bones and renal excretion [1–4]. Parathormone concentrations increase during intense and prolonged exercise [7]. This increase is associated with a decrease in the concentration of Ca++ and with an increase in the concentration of H+ and catecholamines in the plasma induced by exercise [8].

The adrenal gland is an endocrine gland whose main responsibility is to regulate stress responses such as exercise. Adrenal medulla hormones important in the context of exercise are adrenaline and noradrenaline and adrenal cortex hormones aldosterone and cortisol. Adrenaline (epinephrine) causes a weak contraction of muscle blood vessels, an increase in cardiac output, and the intensity of metabolism, which is primarily related to gluconeogenesis in the liver and muscles [30]. Under the influence of adrenaline, all adrenergic receptors are stimulated, which causes a positive inotropic effect on the heart and increases heart rate, heart contractility, blood pressure, and blood flow in the kidneys [31]. At the same time, blood circulation in the digestive organs decreases, and circulation in the skeletal muscles and heart increases. The bronchi dilate, and breathing rate increases, which increases the concentration of oxygen in the blood. In addition, an increased amount of glucose is released from the liver and becomes available for conversion into energy in the muscles [30,32]. Noradrenaline (norepinephrine) has a similar effect as adrenalin. Under the influence of noradrenaline, vasoconstriction of blood vessels occurs, which results in an increase in blood pressure and cardiac output and thus in increased activation of the organism and a faster reaction [30,32]. Aldosterone controls the resorption of sodium and water in the kidneys, helps in the balance of electrolytes and body fluids, and regulates blood pressure via renin–angiotensin [33]. Cortisol contributes to the maintenance of blood glucose levels, especially during prolonged exercise. It plays an important role in the metabolism of three main sources of energy: glucose, fatty acids, and amino acids [34]. In the liver, together with glucagon, adrenaline, and noradrenaline, it stimulates the breakdown of glycogen to release glucose into the blood, which achieves a stable level of glucose in the blood, enabling the proper supply of energy to the muscles and brain. In adipose tissue, cortisol stimulates the release of fatty acids into the bloodstream [35–37]. Although fats contribute less than carbohydrates to the supply of energy to the muscles, they are very important during long-term exercise. Cortisol also travels to the muscles where it stimulates the release of amino acids to be used as energy. These amino acids are oxidized by the working muscles or travel further to the liver where they are converted into glycogen, i.e., glucose [35].

The pancreas is a gland that, in addition to participating in the digestive system, secretes two important hormones responsible for the metabolism of glucose, lipids, and proteins. Pancreatic hormones important in the context of exercise are insulin and glucagon. Insulin enables faster entry of glucose into the cells, which provides energy to carry out various processes such as muscle work during exercise [33]. The increased amount of stored glycogen gives the muscles a greater working capacity, which is especially used in

endurance exercises. It stimulates the accumulation of potassium in muscle cells, which participates in the process of protein synthesis and enables a greater accumulation of fluid within the cell itself, which results in greater strength during exercise [34]. Glucagon has an effect on breaking down liver glycogen and increasing gluconeogenesis. In addition, it promotes the breakdown of fats (lipolysis) and proteins [33].

Figure 1 presents a summary of endocrine responses during exercise during pregnancy.

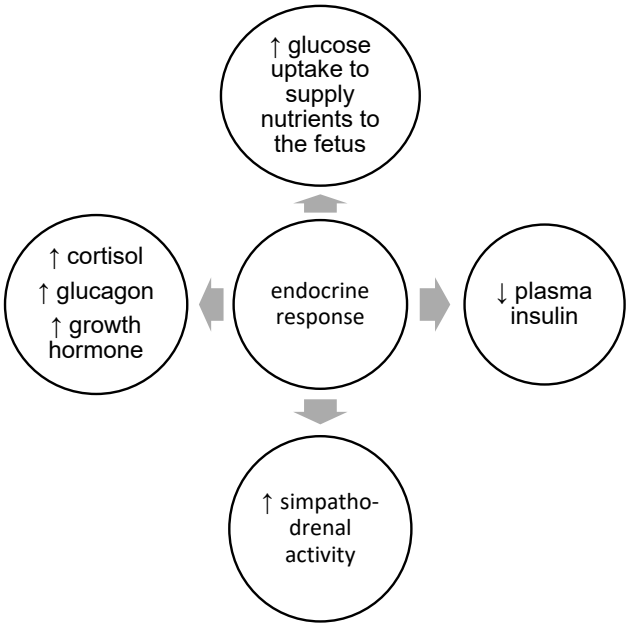


Figure 1. Endocrine response during exercise in pregnancy.

3. Thermoregulation During Exercise

Exercising during pregnancy leads to an increase in body temperature, so-called hyperthermia. It is believed that during submaximal exercise, the adjustment of the pregnant woman's temperature provides thermal protection for the fetus [38]. Clapp suggests an association between the magnitude of exercise-related heat stress for the embryo and fetus with physiological adaptations to pregnancy [39]. For this reason, it is necessary to modify exercise in accordance with the fitness level of the pregnant woman [40].

Physiological mechanisms that enable the release of excess body temperature in order for the body to maintain an ideal temperature during exercise are increased sweating and vasodilation of blood vessels [41]. Sweat evaporation is the primary mechanism by which the body "cools" during exercise. Vasodilatation of the blood vessels of the skin leads to the release of excess heat into the body's environment through the processes of conduction, radiation, and convention, considering the fact that the temperature of the environment is lower than the body's temperature. Exercise brings a greater amount of oxygen to the alveoli, improves lung ventilation, the exchange of oxygen and carbon dioxide, and respiratory functions, increases the strength of the respiratory muscles and blood supply, changes the breathing pattern, and increases the depth of breathing. McMurray et al. indicate that pregnant women have a reduced ability to store heat, have a lowered skin temperature, and increased heat loss through the process of evaporation during exercise. They also propose that pregnancy causes delicate changes in thermoregulation that expand heat production and enhance heat conservation [42].

Exercising during pregnancy causes adaptations of the pregnant woman's cardiovascular system. The major role of the cardiovascular system during exercise is to ensure the supply of a sufficient amount of oxygen to active muscles for work and the removal

of carbon dioxide. In order to fulfill this role, there are numerous changes in the cardiovascular system, especially changes in heart rate, stroke volume, cardiac output, arterial blood pressure, and blood flow [43]. The heart rate increases at the beginning of work and with an increase in the intensity of exercise, and upon reaching the peak individual load, it reaches its peak value. Stroke volume increases during exercise significantly above resting values. During exercise, an increase in venous inflow and, consequently, a larger volume at the end of diastole increases the force of contraction [43]. During exercise, contractility increases due to higher levels of circulating catecholamines (noradrenaline and adrenaline). By increasing the demand for oxygen delivery to active muscles at the beginning of exercise, the cardiac output increases proportionally to the increase in work intensity [43]. Mean arterial pressure increases moderately during exercise. Systolic blood pressure increases in proportion to the increase in exercise intensity, while diastolic blood pressure does not change significantly [44]. An increase in arterial blood pressure, along with an increase in intramuscular osmotic pressure, leads to a loss of plasma from the vascular to the interstitial space and a possible decrease in plasma volume. Intense sweating during high-intensity exercise contributes to an additional decrease in plasma volume [43]. A decrease in plasma volume leads to a decrease in physical fitness, hemoconcentration, and an increase in blood viscosity. The total blood flow in the circulation, and especially the blood flow in the working muscles, by increasing the need for energy during exercise, also increases [44]. Exercise leads to changes in the circulatory system [45]. There is a redistribution of blood towards active skeletal muscles and an increase in body temperature, causing redistribution of blood towards the skin (Figure 2). Circulation exercises lead to increased blood flow through the active muscle, capillarization, and more efficient redistribution of blood. Exercises cause the opening of capillaries during activity, an increase in the heart's functional ability to supply the periphery with blood, the expansion of arterioles in active muscles, a decrease in resistance to blood flow, an increase in muscle blood supply and oxygen extraction from the blood, contraction of smooth muscles in the vein walls, emptying of venous blood stores, an increase in venous inflow to the heart supported by the muscle pump, a reduction in pressure in the chest due to deep breathing, and an increase in vasoconstriction tone in inactive areas [45].

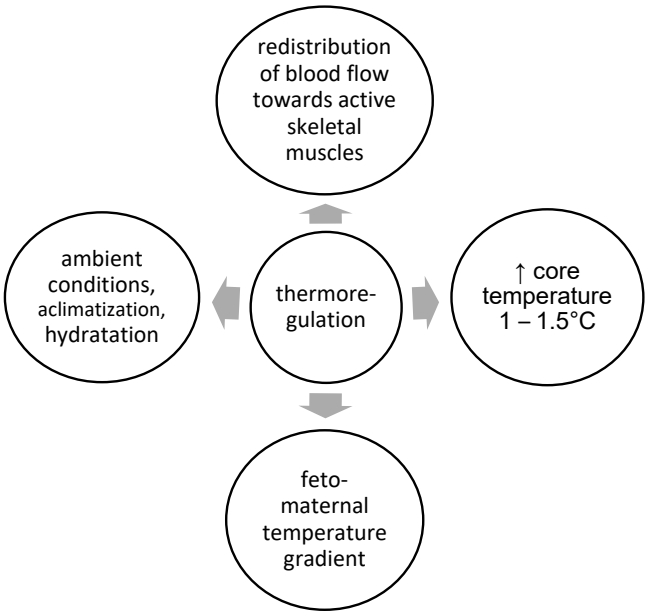


Figure 2. Thermoregulation during exercise in pregnancy.

Also, as a result of exercise, adjustments to the respiratory system occur. During exercise, the role of the respiratory system is connected with an increase in the need to transport oxygen, remove carbon dioxide, and maintain acid–base balance [46]. During exercise, in proportion to the intensity and duration of the exercise, both components of the respiratory minute volume increase (at lower exercise intensities primarily by increasing respiratory volume and at higher ones by increasing breathing frequency), in accordance with the metabolic needs of the active muscles [47]. Under the influence of the respiratory centers in the central nervous system, at the beginning of exercise, there is a sudden increase in respiratory minute volume. The more gradual increases during continued exercise are a response to the current blood chemistry status. The arterio-venous oxygen difference, the amount of CO_2, and the concentration of H+, which stimulates the chemoreceptors, increases, which leads to the stimulation of the inspiratory center [45,48]. Besides the mentioned physiological adaptations of the cardiovascular and respiratory systems during exercise, it is very important to keep in mind the adaptations of body systems during pregnancy (Table 1) as well as the fetal responses (heart rate, fetal movements, and activity) during exercise (Table 2).

Cardiovascular changes during pregnancy include an increase in blood volume, blood pressure, stroke volume, cardiac output, and a decrease in systemic vascular resistance [49]. In the second trimester, the cardiac output is higher by 30–50%, while the stroke volume in the first trimester increases by 10% and 20%, by increasing the heart rate in the second and third trimesters [47,50]. There is an increase in total blood volume by about 40% as a result of an increase in plasma volume by 50% and erythrocytes by 20%. The cardiac output increased by 40% and the stroke volume by 34% [47,50]. Also, there is a change in respiratory volume and capacity, an increase in breathing frequency, and minute ventilation.

The mentioned changes and adaptations of body systems during pregnancy and during exercise must be considered when creating an exercise program during pregnancy. Mothers' responses to exercise training are based on the duration and intensity of exercise, the nutrient profile, and the level of fitness [5,7,9]. Exercise in pregnancy should utilize the FITT principle (frequency, intensity, time, or duration of the activity and the type or modality of exercise) to be safe for the mother and fetus. Thus, when creating an exercise program, the modality of maternal exercise, the gestational age, and the fitness level of the pregnant woman are crucial. Pregnant women need to exercise within their boundaries that do not cause discomfort or stress and should, as pregnancy progresses, be prepared to moderate the intensity and duration of their exercise programs to avoid risks and injury. It is advised that pregnant women should not practice high-intensity exercise programs when pregnant, but moderate exercise is beneficial to both mother and fetus [5].

Table 2. Fetal responses during exercise during pregnancy.

Author/s and Year	Fetal Responses
Clapp and Rizik (1993) [39]	Placental volume increases during the first 24 weeks of pregnancy in pregnant women who exercised at constant doses.
Wolfe et al. (1999) and Bell et al. (1995) [2,17]	Intense, excessive, and inappropriate exercise in pregnancy can affect chronic adaptations and fetal development.
Watsona et al. (1991) and Carpenter et al. (1988) [5,51]	Presence of fetal bradycardia during high-intensity exercise, especially in untrained pregnant women at submaximal loads, and increased fetal movements after exercise.
Wolf et al. (1999) and Watson et al. (1991) [2,52]	Incidence of 15–20% fetal bradycardia after intensive exercise during pregnancy. Fetal bradycardia is a reflex vagal response to significant hypoxia due to maternal hypotension and/or decreased uterine blood supply.
Manders et al. (1997) [51]	Presence of fetal bradycardia 20 min after exercise.

Table 2. *Cont.*

Author/s and Year	Fetal Responses
Wolfe et al. (1999), Brenner et al. (1999) and Webb et al. (1994) [17,45,51]	Higher incidence of fetal exercise tachycardia at the end of the second trimester thought to result from maturation of the fetal autonomic nervous system. Higher frequency of fetal acceleration at the end of the third trimester as a result of increased fetal activity at the end of pregnancy. Gestational age affects fetal heart rate.
Brenner et al. (1999) [45]	Depending on the duration of hypoxia, the fetus may develop bradycardia, tachycardia, heart rate acceleration, increase in heart rate deceleration frequency, and/or reduction in heart rate variability, especially in the third trimester.
Clapp (1993) [39]	The possibility of a teratogenic effect of exercise on the fetus when the body temperature rises above 39.2 °C, especially in the first trimester.
Artal (2003) and Soultanakais-Aligiani (2003) [5,17]	The importance of thermoregulation during exercise in pregnant women due to possible adverse effects on the fetus (especially during the embryogenesis phase). The body temperature of a pregnant woman increases proportionally to the intensity of exercise, and an increase in the body temperature of a pregnant woman above 39 °C has a teratogenic effect.
Rieman et al. (2000) [17]	An increase in the basal temperature of a pregnant woman affects the cellular distribution of the embryo, resulting in teratogenic effects, neural tube defects, and congenital defects, especially in the first trimester.
Soultanakais-Aligiani (2003) [17]	Chronic exposure to elevated body temperature in late pregnancy leads to IUGR due to reduced uteroplacental flow and placental insufficiency.
McMuray and Katz (1990) [18]	Consequences of hyperthermia during exercise in pregnancy are a 10% incidence of anencephaly in the period 24–27 days from conception, microphthalmia, increased preeclampsia at delivery, abnormal fetal EEG, fetal hypotonia, increased frequency of occipital encephalocele between 18th and 28th day from conception, defects in the CNS of the fetus when the body temperature rises above 38.9 °C between the 4th and 14th gestational weeks.
Laburn et al. (2002) [17]	Increasing or decreasing umbilical and uterine flow can increase or decrease placental heat loss. When fetal production and heat loss are in balance, the body temperature of the fetus is 0.5 °C above the body temperature of the pregnant woman, which is known as the maternal-fetal temperature gradient. Loss or reduction in the gradient is associated with fetal distress. The reversal of the fetal–maternal heat gradient is caused by an increase in the mother's basal temperature to the level where it has a teratogenic effect on the development of the fetus (increase in body temperature 1.5–2.5 °C).
McMuray et al. (1993) [42]	Importance of umbilical and uterine flow as essential media for loss of fetal body temperature. If the hyperthermia is 2 °C to 2.5 °C above the basal temperature, the fetal umbilical and maternal uterine flow are significantly reduced (20%) and the fetal arterio-venous oxygen difference is limited.

4. Discussion

The endocrine and thermoregulatory systems integrate physiological responses and play an important role in maintaining homeostatic states at rest and during exercise. Together, coordinated work of the endocrine and thermoregulatory systems contributes to the beneficial effects of exercise during pregnancy.

Changes and adaptations during exercise in pregnancy are conditioned by the influence of numerous metabolic and biochemical events, which act on the target tissues through physiological mechanisms. Many hormones are released during exercise, and a variety of cells are responsible for a number of different responses.

During exercise, a series of physiological changes take place as a response of the pregnant woman's body to increased demands, especially for securing and supplying energy for work, removing excess metabolites and generating thermal energy, and restoring and establishing homeostasis during rest after exercise. However, there are many factors

(endogenous and exogenous) upon which the magnitude of changes under the influence of regular exercise depends, such as genetic factors, age, and individual sensitivity of the pregnant woman to the stimulus of exercise, type of exercises (aerobic exercises, resistance exercises, and endurance exercises), exercise characteristics (intensity, frequency, and duration), etc. [49]. Regular exercise of the appropriate type (especially aerobic exercise) increases physical fitness primarily by improving the functional capacity of the transport system for oxygen, energy substances, and regulatory mechanisms of the endocrine and nervous systems. Acute cardiovascular response to aerobic exercise during pregnancy is similar to that noted in the general population: increased heart rate, stroke volume, and cardiac output, with little to no change in blood pressure [4,7]. It is believed that regular aerobic exercise during pregnancy contributes to the improvement in overall cardiovascular function. Pregnant women appear to have a lower resting heart rate, as well as increased heart rate variability and cardiac output, in response to regular aerobic exercise, despite pregnancy-related increases in sympathetic control and regardless of body mass index [8,9,44]. It seems that the changes in response to aerobic exercise during pregnancy are probably due to an increase in autonomic control, as indicated by overall heart rate variability [11]. Also, similar to the response to aerobic exercise is the lack of change in blood pressure before and after acute resistance exercise during pregnancy. It is believed to be a consequence of the peripheral vasodilatation that occurs during pregnancy [8,11]. Also, in pregnant women who regularly perform aerobic exercise, there is an improvement in the regulation of lipids in the blood. Also, aerobic exercise during pregnancy contributes to the improvement in aerobic submaximal capacity and general health improvement, reducing the risk of adverse conditions, reducing complications during labor and delivery, and reducing the mother's recovery time [8].

Although numerous studies investigate the increase in maternal strength and flexibility due to participation in resistance exercises during pregnancy, some studies point to cardiovascular effects [8,23]. Cardiovascular responses (i.e., blood pressure before, during, and after exercise) to strength exercises in pregnant women are similar to those noticed in non-pregnant women [8,29]. Likewise, there is an increase in heart rate during strength exercises, while blood pressure is highest when performing strength exercises using larger muscle groups. Like aerobic exercises, resistance training has no influence on maternal blood pressure [8].

Under the influence of endurance exercises, a series of metabolic changes occur, such as an increase in the ability to oxidize free fatty acids as a source of energy, which leads to the so-called saving of muscle glycogen. This delays the onset of muscle fatigue and increases endurance. Aerobic endurance exercises reduce the accumulation of lactic acid during submaximal loads, thereby delaying the onset of fatigue and hyperpnea [44]. Resistance exercises stimulate the development of new capillaries in the muscles (thereby increasing the density of the local capillary network and thus the perfusion capacity of the muscle tissue) as well as an increase in muscle mass, i.e., the cross-section and total volume of the muscles [44].

Adjustments in thermoregulation during exercise in pregnancy lead to more efficient performance of physical activity in pregnant women. They ensure numerous benefits that exercise during pregnancy has for both the pregnant woman and the fetus [50]. From the beginning to the end of pregnancy, during exercise, there is an increase in the response to temperature loss (evaporative—and dry—skin blood flow and temperature) with an increase in cardiac output, blood volume, and reduced vascular resistance [52]. There are two possible influences associated with high levels of maternal heat production. The first appears very early in pregnancy and is linked to the potential teratogenic effects of elevated body temperature [9,17]. A lower intensity or shorter duration of exercise or

activities carried out in conditions where there is rapid and efficient dissipation of maternal heat is recommended in early pregnancy [17,35]. A secondary influence, more likely later in pregnancy, is the influence of the redistribution of maternal cardiac output from the uteroplacental unit to the skin and exercising muscles, fetal oxygen supply, and metabolism and a redistribution of the waste products of fetal metabolism [9,40]. If uteroplacental flow is compromised by inadequate exercise, this can have acute or short-term effects, leading to fetal distress [9,45].

These adaptive changes that occur during regular exercise during pregnancy can explain the increase in physical fitness of the pregnant woman and the benefits of exercise during pregnancy. Exercise during pregnancy has numerous positive effects on the pregnant woman and the fetus. In addition to improving the functional abilities of a pregnant woman, exercise reduces the risk of developing gestational diabetes, hypertension, preeclampsia, peripheral edema, varicose veins, deep vein thrombosis, urinary incontinence, painful conditions of the spine and pelvis, excessive weight gain, and premature birth [50]. The benefits of exercise during pregnancy for the fetus relate to an increase in the amount of amniotic fluid and placental volume, vascular function, faster growth of the placenta, and improvement in neurological development. Also, exercise during pregnancy contributes to the reduction in tiredness, fatigue, insomnia, anxiety, depression, and stress and the improvement in the overall general health of the pregnant woman [50]. According to the guidelines of the American College of Gynecology and Obstetrics, pregnant women are recommended to exercise at least 150 min a week at moderate intensity, a combination of aerobic exercise and resistance exercises at least twice a week.

There are some limitations to this review. First, it has only considered studies in English. Mainly, randomized controlled trials narrative and systematic reviews were included, which may have limited its compared hensiveness. Secondly, in the literature, there is a paucity of data on thermoregulatory and endocrine responses during exercise during pregnancy by trimester. This review provides insight into thermoregulatory and endocrine responses, which is important for exercise prescription in clinical practice. It reassures and increases confidence in the prescription of exercise during pregnancy. More research is needed to determine thermoregulatory and endocrine responses during exercise by trimester and the extent to which modes of exercise provide any long-term benefit to maternal and fetal health.

5. Conclusions

Endocrine and thermoregulatory responses enable the body to be prepared for exercise and help clinicians modify exercise programs individually for each pregnant woman. They also enable the adjustment of the type of exercise, intensity, duration, and frequency of exercise according to the level of the physical condition of the pregnant woman and the week of pregnancy. Different modes of exercise throughout pregnancy have been shown to be safe and efficacious for mother and fetus. Further research will deepen existing information and bring new knowledge about thermoregulatory and endocrine responses during exercise during pregnancy.

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