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Review article

How to HIIT while pregnant? The protocol characteristics and effects of high intensity interval training implemented during pregnancy – A systematic review

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Abstract: There is strong scientific evidence that prenatal physical activity of moderate-to-high intensity is a prerequisite of the proper course of pregnancy, childbirth and fetus development. However, to date little data have been available on high intensity interval training (HIIT) performed during pregnancy.

Following the PRISMA guidelines, this systematic review aimed at: first, to characterize HIIT protocols used or planned to be implemented during pregnancy; second, to determine their training effects on participant's health and obstetric outcomes. We included nine original works and three clinical trials in the analysis.

The HIIT protocols substantially differed in terms of the training components (type, intensity, frequency, duration and progression) and the structure of intervals (intensity and time of workout and recovery intervals). Our most important finding is that performing HIIT during pregnancy is safe in terms of obstetric outcomes and well tolerated by pregnant participants, while providing them with the enjoyment of exercise. HIIT interventions either led to an improvement in selected maternal and fetal health parameters or had no impact. No adverse effects were observed.

Pregnant women may benefit from HIIT programs in the same way as other populations. Evidence-based recommendations on prenatal HIIT should be developed and promoted worldwide among pregnant women, exercise and health professionals.

Keywords: women; exercise; physical activity; prenatal care; fetal development; obstetrics.

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1. Introduction

Current guidelines published by credible obstetrics, gynecology and sports medicine institutions, including the World Health Organization, agree that physical activity in pregnancy is safe and desirable in the absence of obstetric and medical complications or contraindications [1–10]. Moreover, recommendations on the potential continuation of a physical activity exceeding the recommended minimum level of 150-minute moderate-to-vigorous physical activity per week or of high intensity have been much more popular for around 5 years [11]. However, there is no information on prenatal high intensity interval training (HIIT) programs in the above-mentioned documents.

HIIT has been one of the ten top fitness trends all over the world in the last decade [12]. There is a variety of HIIT protocols: they are based on short work intervals (<60 s – 8 min) of vigorous (70–90% of the maximal heart rate or 14–16 of the 6–20 Borg's rate of perceived exertion scale – RPE) to high intensity (≥90% of the maximal heart rate or ≥17 of the 6–20 RPE) interspersed with active (40–70% of the maximal heart rate or 8–13 of the 6–20 RPE) or passive (cessation of movement) recovery periods (of 1–5 min) [13]. Numerous studies have already demonstrated health benefits of HIIT programs in various populations, including overweight or obese adults [14], populations with cardiac or metabolic disorders [15], elderly people with dementia [16] and cancer patients [17]. Promising outcomes of HIIT interventions on the improvement of reproductive functions have been observed both in women [18] and men [19, 20] with infertility. However, to date little reliable data have been available on HIIT performed during pregnancy. The question appears whether pregnant women will enjoy similar benefits from HIIT participation as non-pregnant populations do, and is this type of training safe for them?

The lack of popularity of HIIT programs for pregnant women may be a consequence of conservative guidelines, issued 30 years ago, suggesting that exercising women should reduce their habitual levels of exertion in pregnancy and refrain from initiating strenuous exercise programs [21]. In the 1990s, it was widely believed that pregnant women should avoid anaerobic training like sprinting or interval work [22]. Such recommendations were based, among others, on the results of scientific studies demonstrating the negative effects of hard physical work, combined with undernutrition, on the development of pregnancy in laboratory animals [23, 24]. Fortunately, given the subsequent evidence from human population about the positive impact of prenatal exercise on maternal and child health, the question is not "if" but "how" pregnant woman should exercise [21].

Due to the popularity of HIIT in general women population, probably at least some of them would like to continue their HIIT regimes after getting pregnant. Nagpal et al. [25] noted that because of the lack of evidence-based information pregnant women themselves may search online to inquire about participation in HIIT. Their study has shown that publicly accessible online information on HIIT during pregnancy does not adhere routinely to evidence-based safety recommendations for prenatal exercise. Therefore, reliable guidelines on this topic should be developed and disseminated worldwide. This paper is the first step of this concept. Based on a systematic review of experimental studies and clinical trials registers, we aimed at: first, to characterize HIIT protocols used or planned to be implemented during pregnancy; second, to determine their training effects on participant's health and obstetric outcomes.

2. Materials and Methods

We worked in accordance with "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews" to find material for analysis [26]. We searched the following bibliographic platforms and databases: PubMed, Scopus, Medline and Web of Science Core Collection via the Web of Science platform, and also Academic Search Ultimate, Medline and SPORTDiscus with Full Text via the EBSCO Searching platform. Using the terms "pregnancy or pregnant or prenatal or antenatal or perinatal" and "HIIT or high intensity interval training", we found 136 records. After removing duplicates and papers irrelevant to the selected topic (judging on the abstracts), we included four papers in the analysis [27–30]. Based on the reference lists presented in these four papers we included additional five studies [31–35].

With the same searching terms we also searched the International Clinical Trials Registry Platform (ICTRP), which currently contains clinical trials records from the following data providers: Australian New Zealand Clinical Trials Registry (ANZCTR), Brazilian Clinical Trials Registry (ReBec), Chinese Clinical Trial Register (ChiCTR), Clinical Research Information Service (CRiS), Republic of Korea, ClinicalTrials.gov, Clinical Trials Registry – India (CTRI), Cuban Public Registry of Clinical Trials (RPCEC), EU Clinical Trials Register (EU-CTR), German Clinical Trials Register (DRKS), Iranian Registry of Clinical Trials (IRCT), ISRCTN, Japan Primary Registries Network (JPRN), Pan African Clinical Trial Registry (PACTR), Peruvian Clinical Trials Registry (REPEC), Sri Lanka Clinical

Trials Registry (SLCTR), Thai Clinical Trials Register (TCTR) and The Netherlands National Trial Register (NTR). We added three registered trials to this review work [36–38].

The date of the last search was on 30 December 2021. We did not specify the earliest publication date, taking the widest year range available in individual databases. The records found were published between 1993 and 2021. All included papers and clinical trials had to be published in English. Three independent researchers reviewed the collected records. In case of disagreement, we reached the consensus on inclusion or exclusion by discussion. We have presented the process of selecting papers and clinical trials for analysis in Figure 1.

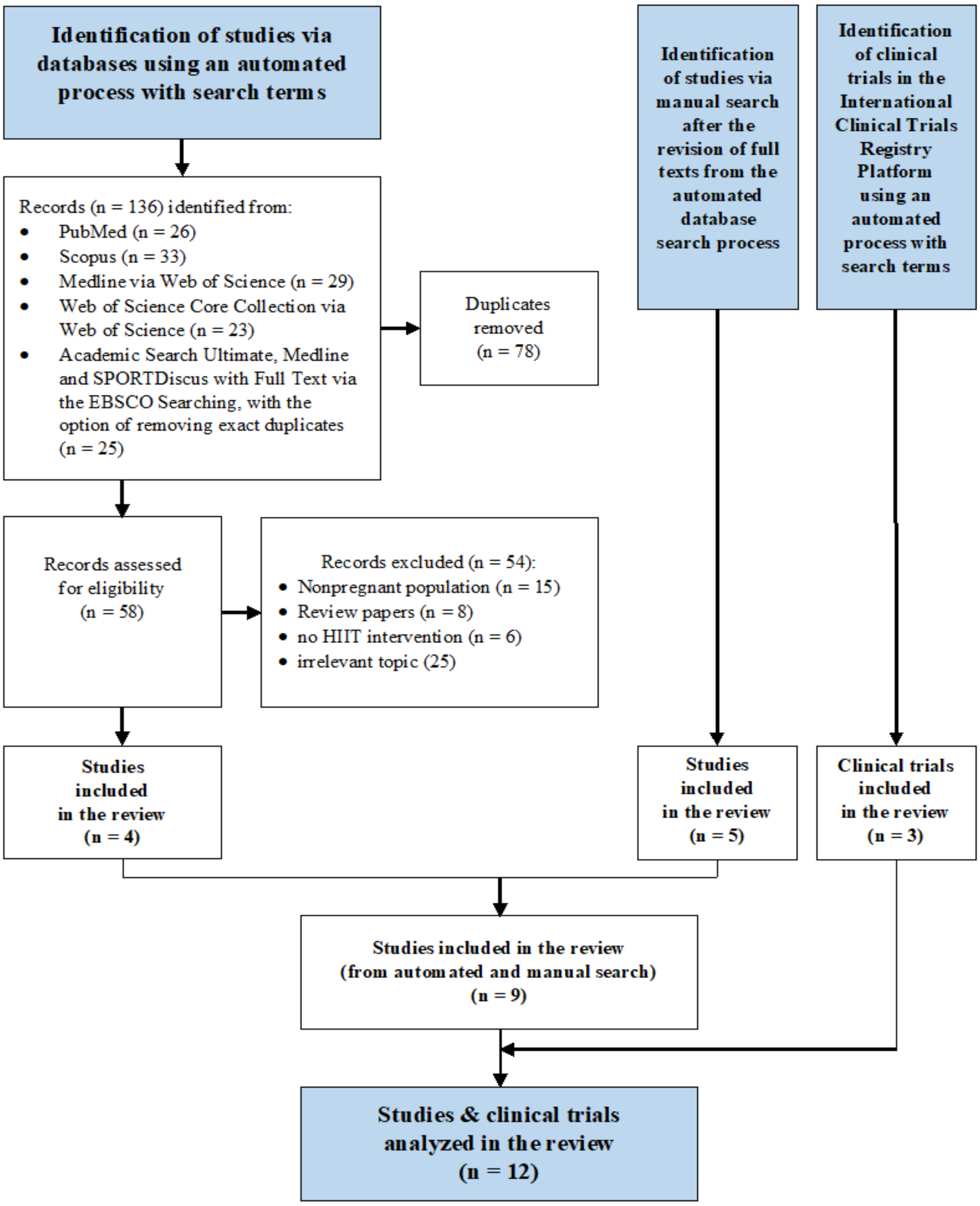

Figure 1. The process selecting studies and clinical trials for analysis.

We followed the PICO (Population, Intervention, Comparison, Outcome) format to structure the eligibility criteria and the process of material revision. We included experimental research work carried out or planned to be conducted in pregnant populations (human or animal) subjected to HIIT (whether it was a one-time training session or a long-term training process). We collected data on the population characteristics (e.g. sample size, stage of pregnancy, subgroups, including comparative groups), study arms and the intervention effects analyzed (both primary outcomes and adverse effects, if any) (Table 1).

Table 1. The characteristics of studies included in the analysis.

Author, year	Population subjected to HIIT					Study arms/ interventions	Primary outcome of the study	Adverse effects
	Type	Total (n)	Exp (n)	Con (n)	wg			
Kardel & Kase [31], 1998[1] Kardel [32] 2005[1]	Women athletes	42 41	20	21 20	17	Two arms: high-volume exercise vs. medium-volume exercise groups	Fetal development and birth outcomes, Maternal pregnancy and postpartum body weight and skin fold, resting and working HR, oxygen consumption, blood lactate and fatigue	None observed
Salvesen et al. [33], 2012	Women athletes	6	6	N/A	23-29	One arm: high intensity interval treadmill running	Fetal wellbeing and uteroplacental blood flow during and post-exercise	None observed
Halse et al. [34], 2014[2] Halse et al. [35], 2015[2]	Women	40	20	20	29 ± 1	Two arms: continuous moderate-intensity, vigorous interval cycling exercise combined with conventional management of GDM vs. conventional management of GDM alone	Maternal glucose metabolism, Maternal aerobic fitness, weight gain, self-reported mobility, attitude toward prenatal exercise, obstetric and neonatal outcomes	None observed
Songstad et al. [27], 2015	Female rats	48	24	24	3 weeks before pregnancy	Two arms: HIIT vs. sedentary groups	Maternal cardiac function, development of fetuses and placentas, gene expression, oxidative stress and total antioxidant capacity	None observed
Ong et al. [28], 2016	Women	12	The same group underwent two subsequent interventions		30 ± 1	Two interventions: high intensity interval cycling vs. continuous cycling	Maternal energy expenditure and enjoyment of exercise	Not reported
Mohammadkhani et al. [29], 2020	Female rats	32	24	8	7 weeks before pregnancy	Four arms: three exercise groups (who exercised 1. only before pregnancy, 2. both before and during pregnancy, 3. only during pregnancy vs. control, sedentary group	Cardiac gene expression, serum lipid profile, and running performance in offspring	None observed
Anderson et al. [30], 2021	Women	14	14	N/A	29 ± 1	One arm: HIIT group	Fetal heart rate and umbilical artery Doppler indices pre- and post-exercise	None observed

HIIT – high intensity interval training, Exp – experimental group, Con – control group, wg – week of gestation at recruitment; HR – heart rate; GDM – gestational diabetes mellitus; N/A – not applicable; [1] – two papers presented data from the same experiment in pregnant elite athletes; [2] – two papers presented data from the same experiment in women with GDM.

In the next step, we analyzed in detail the information on HIIT protocols, in accordance with the ACSM's guidelines on how to design exercise programs [39]. We extracted information on basic training components including the type, intensity and time of workout intervals, the type, intensity and time of recovery intervals, the number of sets or repetitions, the number of cycles, rest time between cycles, the frequency of training sessions and the duration of the entire intervention (Table 2).

Table 2. The characteristics of high intensity interval training (HIIT) in pregnancy used in the analyzed studies.

Author, year	HIIT protocol (the main part of the training session)									Frequency & duration of the entire intervention
	Workout intervals			Recovery intervals			Sets/ repetitions (n)	Cycles (n)	Rest between cycles	
	Type	I	T	Type	I	T				
Kardel & Kase [31], 1998[1] Kardel [32], 2005[1]	Stationary cycling, running, walking fast uphill or cross- country skiing	170-180 HR	15 s or 45 s	N/R		15 s	Repeated for 10 min in the medium-volume exercise group and for 15 min in the high-volume exercise group	2	5 min	Three parts: muscle strength training, aerobic interval training and aerobic endurance training; each part two sessions per week from 17 wg until birth and from 7 until 12 weeks postpartum
Salvesen et al. [33], 2012	Running on a treadmill	60-90% VO_{2max}	5 min	Semi-supine position for USG screening	N/A	4 min	3-53	1	N/A	One session
Halse et al. [34], 2014[2] Halse et al. [35], 2015[2]	Stationary upright cycling	75-85% HRmax; 15-16 RPE	15 -60 s	Stationary cycling	55-65% HR_{max}; 9-11 RPE	2 min		Not reported, the sessions lasted from 25 to 45 min, with the duration progressively increased		Three supervised session and two unsupervised sessions per week; 6 weeks, up the 34 wg
Songstad et al. [27], 2015	Uphill running on a treadmill	85-90% VO_{2max}	4 min	Running	50-60% VO_{2max}	2 min	10	1	N/A	Five sessions per week; 3 weeks before and 3 weeks in pregnancy
Ong et al. [28], 2016	Stationary cycling	Max.	15 s	Cycling	65% HR_{max}	3 min	6	1	N/A	One session of 30-min stationary continuous cycling at 65% HR_{max} with six 15-second maximal intervals

Author, year	HIIT protocol (the main part of the training session)									Frequency & duration of the entire intervention
	Workout intervals			Recovery intervals			Sets/ repetitions (n)	Cycles (n)	Rest between cycles	
	Type	I	T	Type	I	T				
Mohammadkhani et al. [29], 2020	Running on treadmill	85-95% VO_{2max}	3 min	Running on treadmill	65% VO_{2max}	N/R	10-15	1	N/A	Five sessions per week; 6 weeks before pregnancy and 3 weeks during pregnancy; the speed and number of bouts increased every week
Anderson et al. [30], 2021	Resistance circuit training	Max.	20 s	Marching	Self-regulated	60 s	3 cycles		2 min	One session

HIIT – high intensity interval training; I – intensity of training, T – time; HR – Heart Rate; VO_{2max}; wg – week of gestation; Max. – maximal intensity according to participants' individual assessment of physical exertion; N/R – not reported; N/A – not applicable; [1] – two papers presented data from the same experiment in pregnant elite athletes; [2] – two papers presented data from the same experiment in women with GDM

As the authors studied different effects of HIIT interventions in both mothers and fetuses in the analyzed studies, and because of the small number of works included in this review, we did not perform any statistical syntheses.

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3. Results

3.1. The characteristics of the study populations

We included nine papers presenting outcomes from seven experiments [27–35] in the review analysis of HIIT protocols during pregnancy (Table 1). The HIIT interventions were implemented in 114 women aged 24 to 41 years old and in 80 female rats aged 8 to 11 weeks old. The size of the research samples was rather small and varied from 6 to 42 women or from 32 to 48 animals. In two experiments, the study participants were top competitive athletes [31–33]; two HIIT interventions were conducted in healthy, recreational exercisers [28, 30] and one in sedentary women, upon diagnosis of gestational diabetes mellitus (GDM) [34, 35]. All study women had singleton, uncomplicated pregnancies and were recruited between the 17th and 31st week of gestation. The HIIT interventions in rats started three [27] or seven [30] weeks before pregnancy.

3.2. The characteristic of HIIT protocols

The HIIT protocols used in the studies significantly differed in terms of training components (Table 3).

Table 3. The characteristics of clinical trial protocols included in the analysis (regarding women).

Study ID	Start date	Study status	Study population		Study arms	Primary outcome of the trial
			Size (n)	wg		
NCT04830995 [36]	2020	C	40	24	Two arms: HIIT vs. diet only groups	Fasting blood glucose and insulin levels
NCT04288479 [37]	2021	R	30	22-26	One arm: HIIT group	Blood flow in fetal veins and arteries
NCT05009433 [38]	2021	R	600	Not specified	Six arms: HIIT vs. MICT vs. standard care pregnant groups vs. HIIT vs. MICT vs. standard care non-pregnant groups	Maternal cardiopulmonary, renal and pelvic floor muscle functions, gait pattern and mobility parameters, glucose and lipid metabolism, body composition, quality of life, pressure pain threshold, stress, depression and anxiety markers; childbirth parameters; child outcomes

HIIT – high intensity interval training; R – recruiting; C – completed; wg – week of gestation at recruitment.

The most common types of exercise were stationary cycling [28, 31, 32, 34, 35] or running on a treadmill [27, 29, 33]. In one study, resistance circuit training was used [30], and in one intervention walking fast uphill or cross country skiing were alternative types of physical activity [31, 32]. The interval workout intensities were set in relation to the values of the heart rate (HR) or the maximal oxygen consumption (VO_{2max}). They were the exact value of 170–180 HR [31, 32], 75–85% of the predicted HR_{max} [34, 35], 60–90% VO_{2max} [33], 85–90% VO_{2max} [27, 29] or maximal intensity based on participants' individual assessment of perceived physical exertion [28, 30]. To determine the values of HR_{max} or VO_{2max}, the pregnant populations underwent exercise tests in five studies [27–29, 31–33], and in two experiments authors used estimated HR values using age-based calculation formula [34, 35] or the reference exercise HR ranges for pregnant women [30]. In five interventions, the recovery intervals were planned as active breaks with lower intensity from 55 to 65% of the maximal exercise capacity [27–29, 34, 35] or with the intensity self-regulated by the participants [30]. The workout intervals lasted from 15 seconds to 5 minutes and the recovery intervals from 15 seconds to 4 minutes and they were performed in one, two or three cycles with a 2-minute or 5-minute break between them. In three studies, the authors assessed the acute effects of one-time HIIT sessions [28, 30, 33]. Halse et al. [34, 35] conducted 6-week HIIT intervention. The protocol by Kardel [31, 32] covered the period from the 17th week of gestation until birth and later from the 7th until the 12th week postpartum. Only the training interventions in animals were carried out from the very beginning of pregnancy and continued until 2–3 days prior to term [27] or until birth [29].

3.3. The characteristic of HIIT interventions outcomes

In four experiments, the authors assessed the effectiveness of several-week-long HIIT programs [27, 29, 31, 32, 34, 35]. Three other studies evaluated acute effects of a one-time HIIT session [28, 30, 33]. No detrimental impact of prenatal HIIT on obstetric outcomes have been observed in six of the seven experiments. In the remaining study, we only found information that the HIIT session was well tolerated by pregnant participants. In two studies, the authors analyzed the level of enjoyment from participation in HIIT, showing that pregnant women were more favorable towards HIIT compared to moderate intensity continuous training (MICT) programs [28, 30].

The outcomes of HIIT interventions were compared to groups participating in exercise programs of lower intensity or training volume [31, 32], sedentary [27, 29] or standard care groups [34, 35]. In two experiments, HIIT was the only intervention [30, 33], and in one study, women underwent two subsequent interventions: continuous moderate intensity cycling and later high intensity interval cycling [28].

3.4. The HIIT effects on maternal health

The study by Kardel [32] aimed at defining a safe training regime for the maintenance of fitness in top-level female athletes during pregnancy. In the high-volume exercise group (HEG), resting HR increased significantly more steeply with pregnancy progression compared to medium-volume exercise group (MEG). Nevertheless, values for the HEG were always lower or similar to those in the MEG. Both groups presented similar values of working HR, blood lactate concentration and RPE. The MEG showed no significant increases in VO_{2max} from week 17-pre to week 12-post pregnancy, whereas in the HEG VO_{2max} significantly increased (by 9.1%) over the same period. Improved cardiopulmonary or physical fitness parameters after HIIT intervention were observed also in three other experiments [27, 29, 35]. In the study, maternal cardiac function was not affected by HIIT.

Ong et al. [28] proved that the addition of six 15-second higher intensity intervals to continuous moderate intensity exercise effectively increased energy expenditure in a one-time HIIT session by 28%. In four long-term experiments, maternal weight gain during pregnancy was not influenced by HIIT [27, 29, 32, 34]. Interestingly, Kardel & Kase [31] found a tendency for higher maternal weight gain with lower maternal skinfold thickness in the high-volume exercise group compared to the medium-volume exercise group.

The HIIT intervention by Halse et al. [34, 35] was the only one implemented in pregnant women with a special condition: GDM. The authors observed that capillary glucose concentration was acutely reduced in response to exercise sessions. The group participating in a HIIT program had lower mean daily postprandial glucose concentrations throughout the intervention compared to the group subjected only to the conventional diabetes management. There were no differences in maternal weight gain, glycosylated hemoglobin (HbA1c), and glucose or insulin response to oral glucose ingestion after the intervention.

3.5. The HIIT effects on fetal well-being and childbirth outcomes

In two experiments, fetal wellbeing and uteroplacental blood flow during and after one-time session were analyzed [30, 33]. In the study by Salvesen et al. [33], fetuses kept their heart rate (FHR) within the normal range (110–160 bpm) as long as the mother exercised below 90% of the maximal maternal heart rate (MHR). After warm-up, the mean uterine artery volume blood flow was lower by 60–80% of the initial value and during exercise by 40–75%. FHR dropped below the minimum reference value, and high umbilical artery pulsatility index (PI) occurred when the woman exercised above 90% of the maximal MHR, and the mean uterine artery volume blood flow was less than 50% of the initial value. However, FHR and umbilical artery PI normalized quickly after the mother stopped exercise. Anderson et al. [30] also used continuous fetal heart rate tracings and the pre- and post-exercise umbilical artery Doppler indices: systolic/diastolic ratio (S/D ratio), resistance index (RI) and PI. They observed normal FHR throughout the circuit HIIT session. After exercise, umbilical artery end-diastolic flow was normal, and the mean S/D ratios, RI and PI decreased.

The birth outcomes were assessed in four studies [27, 29, 31, 35]. In the experiment in pregnant athletes by Kardel & Kase [31], high- and moderate-volume exercise groups did not significantly differ in terms of the following birth parameters: onset, duration and mode of delivery, pain control, frequency of perinatal medical complications, 1- and 5-min Apgar scores, infant birth weight and placental weight. There were no preterm deliveries, neonatal intensive care unit (NICU) admissions or fetal complications amongst participants of this study. Similarly, Halse et al. [35] did not find substantial differences between women with GDM participating and not participating in HIIT intervention in the following obstetric outcomes: onset, duration and mode of delivery, gestational age at delivery, incidence of preterm birth, newborn anthropometrics (weight, length, and head circumference) and 1- and 5-min Apgar scores.

In the animal studies, gene expression [27, 29] and exercise performance in offspring were also assessed [29]. Songstad et al. [27] found that HIIT did not affect either fetal weight, crown-rump length, placenta weight, placental efficiency (calculated as a ratio between fetal and placental weight), fetal heart weight or total antioxidant capacity in the fetal tissues. However, some genes related to oxidative stress were altered. HIIT led to a significant increase in expression of superoxide dismutase (SOD1), vascular endothelial growth factor B (VEGF-B) and tissue inhibitor of metallopeptidase 3 (TIMP3) in fetal hearts, and a decreased expression of endothelial nitric oxide synthase (eNOS), hypoxia-inducible factor 1α (HIF-1A) and glutathione peroxidase 4.2 (GPx4.2) in fetal livers. In the second animal study by Mohammadkhani et al. [29], the maternal HIIT was related to significantly lower weight gain in rat pups and their better running speed and distance at 10 weeks old, compared to offspring of sedentary mothers. Maternal HIIT also improved the pups' lipid profile, significantly decreasing serum levels of cholesterol (Cho) and low-density lipoprotein (LDL). Another outcome of this study was that HIIT during pregnancy led to a substantial increase in cardiac Sirtuin 6 (Sirt6) gene expression and a decrease in insulin growth factor 2 (IGF-2) gene expression in the heart.

3.6. The characteristics of registered clinical trials

We included three clinical trials records [36–38] with HIIT intervention in pregnant women. One clinical trial was already completed in April, 2021 at the Cairo University, Egypt [36]. The other two are at the recruitment stage [37, 38] (Table 3). They are being conducted at the Norwegian University of Science and Technology, Norway [37] and at the Gdansk University of Physical Education and Sport, Poland [38]. The HIIT interventions, similarly to already performed studies, substantially differ in terms of training components and interval structure (Table 4). The duration of intervention varies from a one-time session [37] to a long-term program implemented throughout pregnancy and one year postpartum [38]. In one trial, apart from the duration and frequency, the authors did not provide more details on the training components of the HIIT intervention [36].

Table 4. The characteristics of high intensity interval training (HIIT) in pregnancy used or planned in the analysed clinical trial protocols.

Author, year	HIIT protocol (the main part of the training session)									Frequency & duration of the entire intervention
	Workout intervals			Recovery intervals			Sets/ repetitions (n)	Cycles (n)	Rest between cycles	
	Type	I	T	Type	I	T				
NCT04830995 [36]	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	Three sessions per week; 4 weeks

Author, year	HIIT protocol (the main part of the training session)									Frequency & duration of the entire intervention
	Workout intervals			Recovery intervals			Sets/ repetitions (n)	Cycles (n)	Rest between cycles	
	Type	I	T	Type	I	T				
NCT04288479 [37]	N/R	High[1]	30 s	N/R	Low-to-mode-rate[1]	2 min	8	N/R	N/R	One session
NCT05009433 [38]	N/R	85-90% VO_{2max}	30-60 s	N/R	N/R	30-60 s	N/R	N/R	N/R	Three sessions per week in 8-week cycles until delivery, after delivery 3-month cycles until one year postpartum

HIIT – high intensity interval training; I – intensity of training, T – time; [1] – not specified how it will be determined; N/R – not reported.

The primary outcomes to be assessed are fasting blood glucose and insulin levels [37] blood flow in fetal veins and arteries [36] and a wide spectrum of physiological, functional and psychological markers of pregnancy disorders and non-communicable diseases in mothers and offspring [38]. We have found no papers based on the outcomes of the above-mentioned clinical trials in the searched scientific databases.

4. Discussion

To implement the first goal of this work, we characterized the HIIT protocols performed by pregnant women or animals in experimental studies. They substantially differed in terms of the structure of intervals. The workout intervals lasted from 15 seconds to 5 minutes with the intensity of 60–95% of HR_{max} or VO_{2max}. The recovery intervals, apart from one study [29], were implemented in an active form with the intensity of 50–65% of HR_{max} or VO_{2max} and went on from 15 seconds to 3 minutes. Such an interval structure is in line with the definition of HIIT directed at other populations [13]. The participants performed 1, 2 or 3 cycles of intervals. Also, other training components: type, intensity, frequency, duration and progression of exercise varied between studies, giving different exercise stimuli in the studied groups.

Our most important finding emerged from the realization of the second aim of this work: HIIT programs, regardless of their training components and intervals structure were well tolerated by pregnant participants and safe in terms of obstetric outcomes. It should be added that the safety of HIIT has been proven in various populations: from female elite athletes, through recreational exercisers to sedentary women. The authors did not find any detrimental effects, either acute or long-term, of prenatal HIIT in any of the analyzed studies. In contrast, numerous health, functional and psychosocial benefits have been observed in both mothers and offspring. Thus, the widespread opinion that pregnant women should forego high intensity interval training [22] is unfounded.

The popularization of HIIT may be important for counteracting too low a level of physical activity or sedentary behavior in pregnant women. Despite recent scientific evidence that regular prenatal physical activity is a prerequisite for the proper course of pregnancy, delivery, puerperium and fetus development, most pregnant women do not follow current recommendations in this regard [40]. They claim lack of time as one of the prime barriers to exercise [41]. As Anderson et al. noted [30], a solution to this problem is to use the inverse relationship between exercise intensity and duration. Therefore, HIIT programs, providing a strong training stimulus in a short time, may overcome this barrier. What is also important, pregnant women found HIIT training to be more enjoyable than traditional aerobic training [28, 30]. In the experiment by Anderson [30], the studied women stated that a HIIT session was more "interesting", "challenging", provided a "better workout" and made time "go faster" because the exercise was "broken up". Halse et al. [35] observed that participation in a HIIT cycling program enhanced pregnant women's attitudes and intentions toward exercise. Training enjoyment is of particular importance because it significantly predicts exercise adherence [42], which consequently may determine desired health benefits.

In the analyzed studies [27, 29, 32, 35], the researchers observed a positive effect of prenatal HIIT programs on maternal cardiopulmonary parameters. These results correspond to the findings from meta-analyses assessing effectiveness of HIIT interventions in the prevention of cardiac diseases in non-pregnant populations [14]. Interestingly, based on the study by Halse et al. [34, 35], prenatal HIIT programs seem to be a useful measure also for the prevention of gestational diabetes mellitus. Better glucose metabolism was observed in women with GDM participating in HIIT compared to the control group receiving conventional diabetes management. This outcome is in line with the systematic review by Campbell et al. [15], who also noted a beneficial impact of HIIT on glucose homeostasis biomarkers in non-pregnant adults. What is also important, in animal studies [27, 29] the implementation of HIIT prior to and during pregnancy had positive intergenerational consequences for the health and physical readiness of offspring. Based on these results, it should be concluded that pregnant women, like other populations, or even more, may benefit from this type of training.

Contrary to the results presented above, in some of the analyzed studies, the authors did not observe the impact of prenatal HIIT on selected health parameters. There was no effect of HIIT on maternal cardiac function in one study [27] and on maternal weight gain during pregnancy in four experiments [27, 29, 32, 34]. When interpreting these data, it is worth referring to meta-analyses indicating that there are no differences between the effects of HIIT and MICT on insulin sensitivity, blood pressure, and body composition [15] and some indicators of the lipid profile [13]. As Wang et al. [14] noted, the training response to HIIT interventions was associated with the training period, training intensity, and session duration. Unfortunately, based on the collected material, it was not possible to state to what extent differences in the selection of training components could change the effectiveness of prenatal HIIT. However, referring to the basic assumptions of planning the training process [39], it is obvious that also in pregnant populations the selection of training components will be of key importance.

The intensity of exercise during pregnancy is particularly controversial. Although the upper limit for the intensity of physical effort for the perinatal period has not been set so far [5], women tend to lower it. One of the reasons is a lack of consensus around the safety of participating in higher intensity training [43]. One of the discussed issues is whether the mother's increased need for oxygenated blood during intense exercise will limit its supply to the fetus and, consequently, negatively affect its development. Two experiments assessing fetal wellbeing and uteroplacental blood flow during and after one-time HIIT session [30, 33] showed that this concern is unjustified. In one study in elite athletes [33], performing three to five submaximal running intervals, with an intensity of up to 90% VO_{2max} did not adversely affect the fetal well-being. Although the temporary fetal bradycardia appeared when the mother exceeded 90% of the VO_{2max} exercise intensity, FHR quickly normalized after the mother stopped exercise. In non-athletes, Anderson et al. [30] observed normal FHR throughout the circuit HIIT session, even though the participants performed 20-second workout intervals at maximal intensity. Interestingly, the authors interpreted the changes in umbilical artery as indicating possible improved fetal perfusion.

It is particularly important from a clinical point of view that women or animals subjected to long-term HIIT programs experience normal labor and delivery and give birth to healthy offspring [27, 29, 31, 35]. According to Songstad et al. [27], this may indicate that the regular short periods of active recovery between bouts of exercise at the anaerobic threshold in HIIT, may protect the fetus and placenta from circulatory stress. The results presented in this review work support and complement findings of meta-analysis by Beetham et al. [43]. The authors concluded that vigorous physical activity during the third trimester is safe in terms of birth and neonatal outcomes. They also pointed out that further research is needed on the effects of vigorous intensity exercise in the first and second trimester, and of exercise intensity exceeding 90% of the maximum heart rate. Two experiments analyzed in this review, although in animal models, were initiated a few weeks before pregnancy and continued until delivery. What is more, in the study by Mohammadkhani et al. [29], pregnant rats exercised with the intensity up to 95% of VO_{2max}, and it positively impacted their pups.

Obviously, interventions similar to the above-mentioned one should be performed in the human population prior to dissemination of recommendations for pregnant women how to participate in HIIT. The next important step is preparing exercise professionals to plan and implement prenatal HIIT programs. Therefore, it is necessary to update the learning outcomes and educational content of professional training for specialists working with pregnant exercisers. Currently, work is underway in an international team to update the European standard for Pregnancy and Postnatal Exercise Specialist [44], as well as to develop an educational program and materials on this topic within the NEPPE Project [45]. Another important issue is education of obstetric care providers. As they have a great influence on patients' health behavior [46], it is critical that they give pregnant women accurate and sufficient information [47], also on prenatal HIIT programs. Pregnant women should be informed that participation in high intensity exercise, following the general recommendations for physical activity during pregnancy, proper caloric intake and hydration, is safe and beneficial [5].

Lack of adequate knowledge among exercise and health professionals may be one of the reasons for the low popularity of prenatal HIIT programs, both in the health-promoting exercise market and in scientific research. Our review highlights a small number of works which were qualified for the analysis, both published articles and clinical trials records (12 items in total). The analyzed experiments do not address many important issues, for example to what extent prenatal HIIT can be used in the prevention of pregnancy complications, other than gestational diabetes, e.g. preeclampsia, dyslipidemia, gestational hypertension or perinatal depression. There is also a lack of data on whether HIIT is an appropriate form of training for women with multiple pregnancies. Further research should be conducted in human populations to determine the effects of prenatal HIIT on the health and development of their children later in life. These issues are planned to be assessed in one 10-year-long clinical trial [38]. The effectiveness of HIIT programs implemented in postpartum women also seems interesting [48].

This review study has some limitations. First, one of the inclusion criteria for the analysis was that the papers or clinical trial records were published in English. It is possible that other prenatal HIIT interventions have been implemented or planned to be implemented, but published in other languages. Second, some works may have been missed due to our selection of the keywords for the search process. Some authors may not have used the name "HIIT" for a training intervention that they used in their experiments, even though it was HIIT. To minimize such a risk, we additionally analyzed the reference lists included in the articles that were indicated by the automatic search engine in the first stage of database searches.

Another weak point of this work is that due to the small number of papers meeting the inclusion criteria and their methodological diversity, we were unable to perform synthetic analyses of prenatal HIIT outcomes. However, the characterized HIIT protocols can be exemplary solutions, both for use by other researchers in experimental work and by exercise professionals in training practice.

5. Conclusions

Until now, HIIT programs have rarely represented training interventions in experimental studies in pregnant populations. The limited number of studies available in scientific databases prevents a synthetic analysis of the impact of HIIT on specific biological or psychosocial indicators of the course of pregnancy, delivery and fetal development. Nevertheless, this review concludes that performing HIIT during pregnancy is safe for both mothers and their offspring. No adverse effects were observed in any of the analyzed works. Taking into account the positive feelings of women from participation in HIIT programs, the ease of carrying them out and the favorable ratio of the time devoted to the intensity of the training stimulus, it is worth popularizing this form of exercise in pregnant women. All the evidence shows that pregnant women can benefit from HIIT programs in the same way as other populations.

In the reviewed studies, HIIT interventions either led to the improvement in selected maternal or fetal health parameters (including metabolism, cardiopulmonary system indices and physical fitness) or had no impact compared to control groups. The differentiated effectiveness of HIIT may result from their diversity in terms of the training components (type, intensity, frequency, duration and progression) and the structure of intervals (intensity and time of workout and recovery intervals). Therefore, it seems necessary to conduct further research, analyzing the effects of specifically planned HIIT on the multigenerational benefits and prevention or treatment of specific perinatal complications. In addition, evidence-based recommendations on prenatal HIIT should be developed and promoted worldwide among pregnant women, exercise and health professionals and obstetric care providers.

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