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# The effects of exercise during pregnancy on placental composition: A systematic review and meta-analysis

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ABSTRACT

*Introduction:* Morphological changes to the placenta occur as the demands of the foetus increase throughout gestation. Physical activity during pregnancy is known to benefit both the mother and infant, however the impact of antenatal exercise training on placental development is less known. The aim of this systematic review and meta-analysis was to investigate the effects of exercise training during pregnancy on measures of placental composition.

*Methods:* Six electronic databases were searched from inception to June 2021 for studies comparing regular antenatal exercise with either usual maternal care or no exercise for its effect on measures of placental morphological composition. Meta-analyses were performed for placental weight and the placental weight to birthweight (PWBW) ratio.

*Results:* Seven randomised controlled trials and two cohort studies were included in the systematic review and meta-analysis (n = 9). There was no significant difference in placental weight (mean difference (MD) = -9.07g, p = 0.42) or the PWBW ratio (MD = 0.00, p = 0.32) between exercise and control groups. Parenchymal tissue volume was higher, represented by an increase in villous tissue, and non-parenchymal volume was lower in women who exercised regularly compared to those that were not exercising during pregnancy.

*Discussion:* Exercise training during pregnancy may not alter placental weight or the PWBW ratio. However, findings from this review indicate that antenatal exercise training can promote advantageous morphological changes to placental tissues.

## 1. Introduction

Placental villous tissue growth peaks at different time periods during pregnancy [1]. Increases in the volume, surface area, and length of the intermediate and terminal villi occur to support the growing demands of the foetus, with the thickness of the villous membrane and the villous tissue surface area contributing to the oxygen diffusing capacity for maternal-foetal gas exchange [1,2]. However, pregnancy complications, such as pre-eclampsia and intrauterine growth restriction (IUGR), can cause abnormal placental growth and development through insufficient uteroplacental perfusion [3–5], leading to adverse maternal and foetal outcomes. While regular physical activity and exercise training during pregnancy may contribute to a reduction in the risk factors of these conditions [6,7], the exact mechanistic effects of exercise training on placental development in healthy or clinical pregnancies have not been widely investigated.

Maternal demographics and behaviours can influence placental, and therefore foetal, health and development [8,9]. Placental weight has been proposed as a marker of the available surface area for maternal-foetal nutrient exchange and is a significant determinant of birthweight and foetal growth in the 3rd trimester [10,11]. Placental weight and birthweight outcomes can be used as a measure of placental efficiency, showing associations with the prediction of the risk of neonatal and maternal morbidity and mortality [12–14]. Research suggests that antenatal exercise training is not detrimental to foetal outcomes, with studies demonstrating increases in gestational age, a decrease or no change in risk of prematurity, and no significant difference in infant birthweight in women that performed regular exercise

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during pregnancy compared to those that were inactive [15–17]. However, whether exercise training during pregnancy influences measurable morphological changes in the placenta is not well known.

The current systematic review and meta-analysis is the first of its kind to investigate the effects of different exercise variables on measures of placental composition in human pregnancies. We aimed to analyse the relationship between exercise training during pregnancy and morphological changes to the placenta, and, if exercise performed in certain trimesters or with different training variables has greater influence on placental changes. The primary aim of this study was to determine the effect of exercise on placental weight, while the secondary aims were to analyse the influence of antenatal exercise on the placental weight to birth weight (PWBW) ratio and volumetric measures of placental composition. We hypothesised that exercise performed during pregnancy would increase absolute placental weight and volume due to an increased growth of placental villous tissues with exercise.

## 2. Methods

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [18] and was registered in PROSPERO (International Prospective Register for Systematic Reviews) under the registration number CRD42021250878.

### 2.1. Search strategy

The electronic databases PubMed, Web of Science, Cochrane Central, Embase, SportDiscus and CINAHL Complete were searched from inception to June 2021 using key terms and synonyms of pregnant women, exercise, and placenta. Boolean operations and truncation were applied to the search strategy and Medical Subject Headings (MeSH) and Emtree terms were used to expand on key terms. Filters were applied to limit the search to academic journals or articles and the English language. Articles in languages other than English were reviewed whereby none were suitable for inclusion based on the selection criteria. The full search strategy used to retrieve the studies can be found in Table S1. The reference lists of the included articles were screened to ensure all applicable articles were included in the review.

### 2.2. Inclusion and exclusion criteria

Studies eligible for inclusion were randomised controlled trials (RCTs), quasi-experimental, cohort studies, and case-control studies. The inclusion criteria consisted of a study involving pregnant women, the performance or measurement of exercise across at least two trimesters, the presence of a control group that only received standard maternal care or did not participate in any exercise training, and placental weight measured at delivery. Studies were excluded if the study was not yet completed, was performed on animals, or if the intervention involved an additional treatment other than exercise. Studies were not included in the review if the data was incomplete and contacted authors failed to provide additional information. If greater than one sub-study from the same cohort met the inclusion criteria, the study with the largest sample size was selected to be included in the review to ensure participant results were not included more than once.

### 2.3. Data collection

Articles retrieved from the databases were exported to Covidence [19] where titles and abstracts were screened by JK after duplicate removal. The full texts were reviewed separately by JK and KB with conflicts resolved through consensus between the two authors. The data were extracted and reviewed independently by JK and KB to gather information relating to study characteristics, population characteristics, intervention and comparator group descriptions, and primary and secondary outcomes.

### 2.4. Quality assessment

The quality of the studies included in this systematic review and meta-analysis were assessed using the Cochrane Risk of Bias Tool for RCTs and the Newcastle-Ottawa Quality Assessment Scale for cohort studies. The quality assessments were performed individually by JK and KB with conflicts resolved between the two authors.

### 2.5. Definitions

The first trimester was classified as 13 weeks of gestation or less, the second trimester as 14–26 weeks of gestation, and the third trimester as ≥27 weeks of gestation [20]. Total placental volume was defined as the volume of the entire placenta following delivery, measured through fluid displacement [21]. Parenchymal volume, also referred to as functional volume, was defined as the total volume of all villi and intervillous space determined through stereological analyses and point counting techniques [21]. The total parenchymal tissue volume represents the functional units of the placenta with key contributions to nutrient and gas exchange to the foetus. Non-parenchymal volume was composed of the remaining structures in the placenta, such as damaged tissue, membranes, decidua, and fibrin, that provide minimal support for foetal demands [21–23]. The PWBW ratio was defined as the ratio between the placental weight and the birthweight, determined by dividing the placental weight (grams) by the birthweight (grams) of the infant [13].

### 2.6. Statistical analysis

The statistical analysis was conducted using the Review Manager 5.4 software [24]. A random effects model was employed due to the difference in distribution of effects across studies, and pooled meta-analyses were performed separately for each outcome. Subgroup analyses were conducted to investigate differences in placental weight, as this outcome was reported most frequently in the included studies. Subgroup analyses explored differences based on study design, exercise performed at various timepoints during pregnancy, different exercise intensities and modalities of interventions, and the type of supervision involved. Mean differences (MDs) were calculated for all continuous variables, with the statistical significance determined by a p-value of $<0.05$.

If more than two exercise groups were present in a study, the groups were combined, whereby the exercise group included all women who performed any type of exercise training during pregnancy. Overall, 80,515 pregnancies were investigated by Hilde et al. [25], however 36, 843 of these pregnancies changed frequency of exercise between the two surveys administered during pregnancy. The number of individuals that changed between frequency groups or from exercising to non-exercising could not be determined, therefore only 32,962 pregnancies were included in the exercise group analysis for this study. The control group involved women who were physically inactive.

## 3. Results

A total of 1,853 articles were identified through the database search (Fig. 1). After filters were applied (journal article and/or English language) and duplicates were removed, 694 articles were screened by title and abstract. The full texts of 71 articles were assessed based on the inclusion and exclusion criteria, with 16 articles eligible for inclusion. Three of these articles were excluded as they involved the same cohort of participants as an already included article. Four studies were then excluded as the required data were unavailable for the primary outcomes of this review. Overall, seven RCTs ($n = 370$) and two cohort studies ($n = 43,732$) were included in the systematic review and meta-

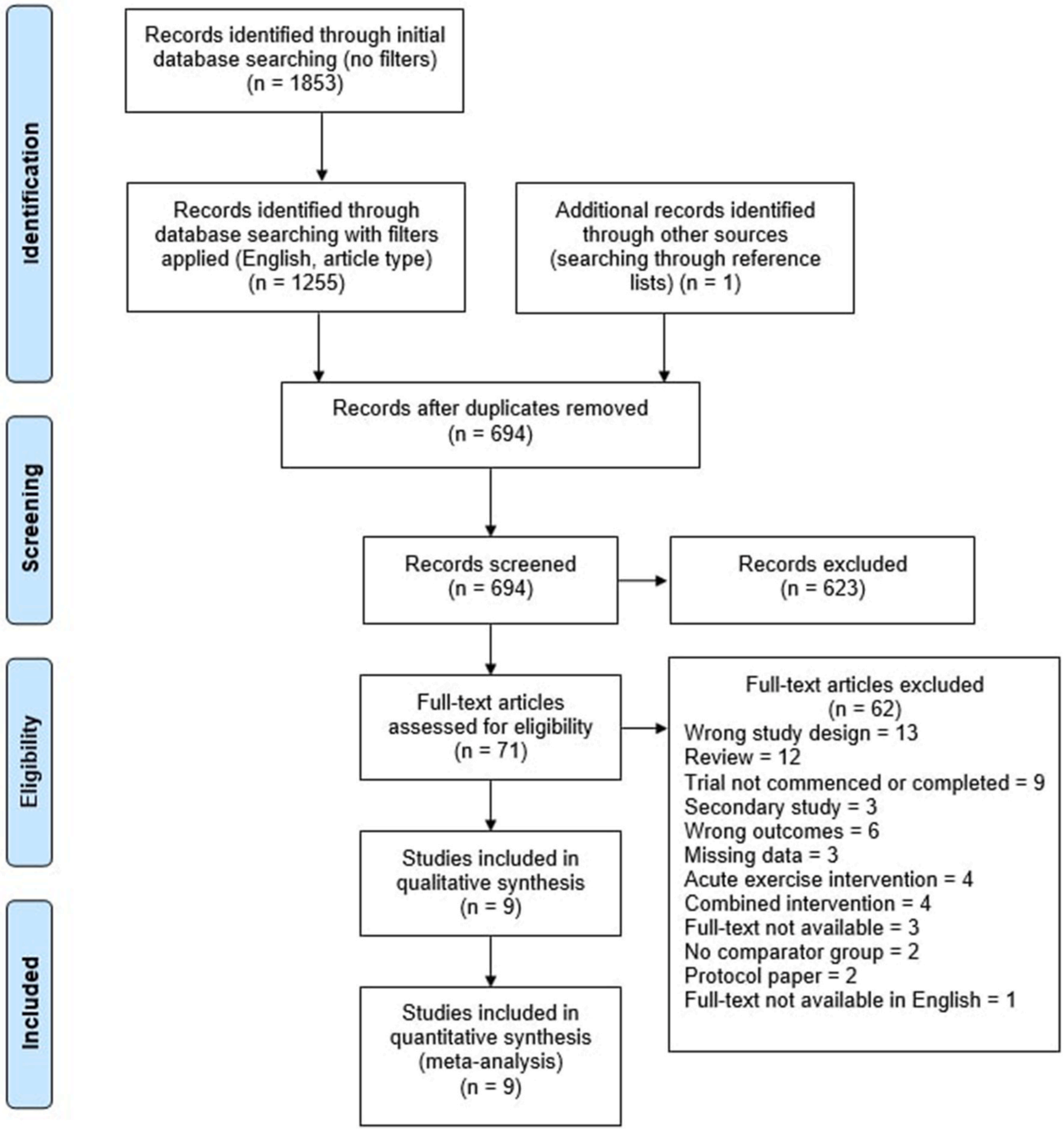


**Fig. 1.** PRISMA flow chart for the systematic review process.

analysis, with a total of 44,102 participants. Summaries of the characteristics of the RCTs and cohort studies are presented in Table 1 and Table 2 respectively. Physical activity reported in the included studies involved only recreational exercise.

### 3.1. Exercise monitoring

Exercise sessions were supervised in five studies [22,26–30], while the interventions by Hardy et al. [27] and Seneviratne et al. [30] involved sessions performed at home. The intensities of the exercise sessions were reported objectively in four studies using heart rate monitors [26,27,29,30]. Three studies used an exercise professional or member from the study team to monitor the intensity through respiratory calorimetry measured every two weeks [22] or the use of the Borg scale of perceived exertion [28,31]. Jackson et al. [21] subjectively collected information on exercise performance from a weekly exercise log, however the intensity was confirmed during field exercise sessions at least once throughout pregnancy.

### 3.2. Adverse events

Eight of the included studies recruited women with no contraindications to exercise at enrolment [21,22,26–31]. No major adverse events relating to the exercise intervention were reported in five of the studies [26,28–31], however, participants in four of the studies demonstrated the threat or presence of preterm birth or other medical contraindications to exercise during the intervention [22,26,28,31]. The authors from three of the included studies reported that there was no indication that the incidence of these conditions was related to the exercise intervention, with two studies including the participants in an intention-to-treat analysis [26,31], and one excluding the participant [28]. Clapp et al. [22] included two participants who experienced preterm birth in their analyses, however, did not report if the incidence was related to the exercise intervention. Three studies made no mention of the presence or absence of any adverse effects due to exercise [21,25,27].

**Table 1**
Summary of the characteristics of the included randomised controlled trials.

| Study (Author, year) | Sample size | | | Population | Length of intervention | Exercise intervention | | | | | Control group | Outcomes comparing exercise to control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Exercise | Control | | Trimesters | Type | Intensity | Duration | Frequency | Adherence to intervention | | |
| Barakat et al., 2018 [26] | 65 | 33 | 32 | Healthy women | 1 to 3 | Combined AT, RT and PFT | Low to moderate | 55–60 min | 3 times/ week | ≥85% | Usual care and not discouraged from exercise | ↔ PW<br>↔ PWBW ratio |
| Clapp et al., 2000 [22] | 46 | 22 | 24 | Healthy women | 2 to 3 | AT | Moderate (55–60% of preconception maximum aerobic capacity) | 20 min | 3-5 times/ week | 12-20 out of 20 sessions per lunar month | Usual care | ↑ PV<br>↑ Parenchymal tissue volume<br>↑ Villous tissue volume<br>↔ Intervillous space volume<br>↓ Non-parenchymal tissue volume |
| Garnæs et al., 2017 [31] | 74 | 38 | 36 | Overweight and obese (BMI ≥28 kg/m$^2$) women | 2 to 3 | Combined AT, RT and PFT | Moderate | 60 min | 5 times/ week | Mean 31.7 supervised sessions (range 0–53), mean 19.2 sessions at home (range 0–72) | Usual care and not discouraged from exercise | ↔ PW<br>↔ PWBW ratio |
| Hardy et al., 2021 [27] | 29 | 21 | 8 | Healthy women | 2 to 3 | Combined AT and RT | Group 1 (n = 6): mild (30% HRR)<br>Group 2 (n = 15): moderate (70% HRR) | Varied based on modality | ≥3 times/ week | ≥70% | Sedentary women who confirmed no participation in a structured exercise program at 34–36 weeks of gestation | ↔ PW<br>↔ BWPW ratio |
| Price et al., 2012 [28] | 62 | 31 | 31 | Healthy women | 2 to 3 | AT | Moderate | 45–60 min | 4 times/ week | 93% | Usual care and told not to exercise | ↔ PW |
| Ramírez-Vélez et al., 2013 [29] | 20 | 10 | 10 | Healthy women | 2 to 3 | Combined AT and RT | Low to moderate | 60 min | 3 times/ week | Mean 80% | Usual care and exercise | ↓ PW<br>↑ BWPW ratio |
| Seneviratne et al., 2015 [30] | 74 | 37 | 37 | Overweight and obese (BMI ≥25 kg/m$^2$) women | 2 to 3 | AT | Moderate (40–59% $VO_2$ reserve) | 15–30 min | 3-5 times/ week | Mean 33% (range 0–85%) | Usual care and exercise | ↔ PW |

AT = aerobic training; BMI = body mass index; BWPW = birthweight to placental weight; HRR = heart rate reserve; PFT = pelvic floor training; PV = placental volume; PW = placental weight; PWBW = placental weight to birthweight; RT = resistance training.

**Table 2**
Summary of the characteristics of the included cohort studies.

| Study | Sample size | | | Population | Length of intervention | Exercise description | | | | Control group | Outcomes comparing exercise to control |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Exercise | Control | | Trimesters | Type | Intensity | Duration | Frequency | | |
| Hilde et al., 2017 [25] | 43,672 | 32,962 | 10,710 | Healthy, overweight, obese, and women with chronic diseases | 2 to 3 | Combined AT and RT | Not reported | Not reported | ≥3 times/ week | No exercise or only strolling at weeks 17 and 30 | ↓ PW with increasing frequency ↔ PWBW ratio |
| Jackson et al., 1995 [21] | 60 | 40 | 20 | Healthy women | Group 1: 1 to 3 Group 2: 1 to 2 | AT | Moderate (>50% of individual maximum capacity) | ≥30 min | 3-5 times/ week | No exercise | ↔ PW ↔ PV ↑ Parenchymal tissue volume ↑ Villous tissue volume ↔ Intervillous space volume ↓ Non-parenchymal tissue volume |

AT = aerobic training; PV = placental volume; PW = placental weight; PWBW = placental weight to birthweight; RT = resistance training.

### *3.3. Quality assessment*

Seven RCTs were assessed using the Cochrane Risk of Bias Assessment Tool (Fig. S1) [22,26–31]. All studies demonstrated high risk of bias for blinding of participants and personnel, which is common in exercise interventions. High risk of 'other bias' was demonstrated in two studies [22,29], in which the authors made no mention to the presence or absence of any conflicts of interest or poorly reported the process for selection of participants or the compliance with the exercise intervention. The blinding of the outcome assessment was not reported by two studies [26,27], and was deemed as high risk for two studies [22,28] which lacked blinding for the collection and measurement of outcomes.

Two cohort studies were analysed using the Newcastle-Ottawa Quality Assessment Scale to determine the risk of bias (Table S2) [21, 25]. Overall, the study by Hilde et al. [25] was rated as average quality and the study by Jackson et al. [21] as low quality. The assessment of selection bias differed, with Hilde et al. [25] containing a cohort of women that may be indicative of the entire pregnant population while the study by Jackson et al. [21] involved a refined cohort of non-smoking pregnant women with a pre-pregnancy weight of between 45 and 70 kilograms, thereby limiting its representativeness. However, the two studies failed to receive a point for the ascertainment of exposure as the information relating to physical activity levels, and subsequent categorisation, were gained through self-report. Jackson et al. [21] did not mention controlling for confounding factors associated with placental weight and therefore did not score a point for this criterion.

### *3.4. Placental weight*

Moderate quality evidence showed that placental weight was not significantly different in women who exercised during pregnancy compared to those that performed no regular physical activity (Fig. 2; p = 0.42). This finding was consistent across study designs, with no significant mean difference observed when comparing the RCTs to the cohort studies (Fig. S2; p = 0.39), as well as when exercise training was performed during different trimesters (Fig. S3; p = 0.47). When comparing supervised exercise training, unsupervised prescribed training and unsupervised habitual physical activity, no significant difference in placental weight was observed between the groups (Fig. S4; p = 0.66).

The subgroup analysis showed no significant difference in placental weight when comparing the effects of low, low-to-moderate, and moderate intensities of exercise (Fig. S5; p = 0.05). When stratified for the different exercise intensities, no significant difference in placental weight was observed between exercise and the control for any of the groups (low: Figure S5.1.1; p = 0.85; low-to-moderate: Figure S5.1.2; p = 0.08; moderate: Figure S5.1.3; p = 0.08).

No statistically significant difference in placental weight was found between exercise modalities (aerobic exercise alone compared to combined aerobic and resistance exercise) (Fig. S6; p = 0.08). When placental weight was stratified for either aerobic exercise alone or combined aerobic and resistance exercise, the pooled estimates showed no significant difference in placental weight between the exercise and

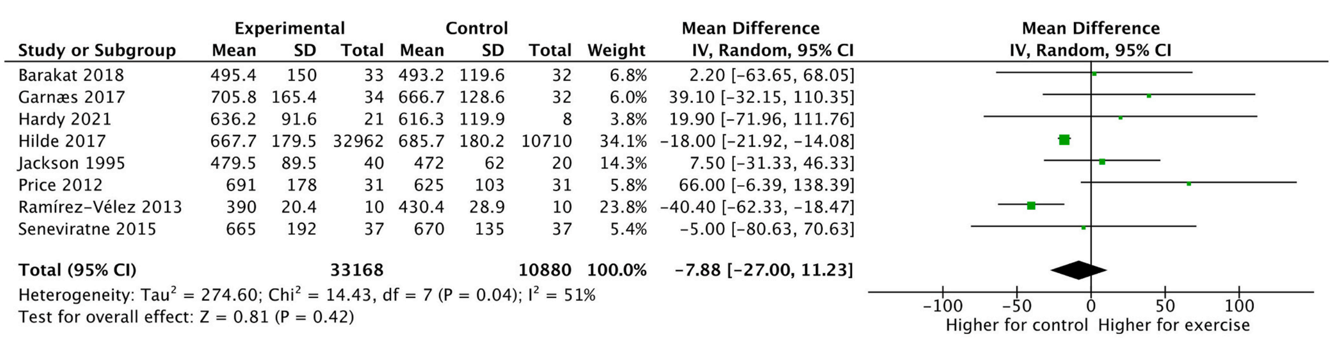


**Fig. 2.** Forest plot of the mean difference in placental weight between exercise and control groups.

the control groups (Figure S6.1.1; p = 0.33; Figure S6.1.2; p = 0.06).

While a subgroup meta-analysis for exercise volume was unable to be conducted, Hilde et al. [25] observed a significant decrease in placental weight with increasing frequency of exercise sessions per week.

### 3.5. PWBW ratio

Of the four studies that reported the PWBW ratio [21,25,26,31], average quality evidence showed no significant pooled mean difference between exercise and control groups (Fig. 3; MD = 0.00, p = 0.32).

### 3.6. Placental volumetric composition

The studies by Jackson et al. [21] and Clapp et al. [22] investigated measures of placental volumetric composition, including total placental volume, parenchymal volume, villous tissue volume, intervillous space volume, and non-parenchymal tissue volume. Low quality evidence from the studies showed differing results in total placental volume with exercise, whereby Jackson et al. [21] observed no change in volume, while Clapp et al. [22] found an increase with exercise during pregnancy. Results from the stereological analyses were consistent across both studies, with a significant increase in total parenchymal tissue and villous tissue volumes, no change in intervillous space volume, and a decrease in non-parenchymal tissue volume observed with antenatal exercise [21,22].

## 4. Discussion

The findings from this study demonstrate no difference in placental weight or the PWBW ratio between women who exercised during pregnancy compared with those who were inactive. However, there was a significant increase in villous tissue volume compared to non-parenchymal volume in the exercising group compared to the control. This indicates that exercise training may contribute to an improvement in placental function through an enhanced ability for nutrient and gas exchange from the placenta to the foetus.

Previous literature has concentrated on placental weight, or the PWBW ratio, as a measure of placental efficiency. However, the findings of the current meta-analysis showed that changes to the morphological composition of the placenta may occur in the absence of a change in placental weight. Variations in placental morphology have been observed in pregnancy-related conditions, with both pre-eclamptic and IUGR pregnancies demonstrating reduced villous tissue area compared with healthy pregnancies [32,33]. One study showed that IUGR pregnancies were accompanied by a reduction in placental weight while no significant change was observed between healthy and pre-eclamptic pregnancies in the same study [33]. Decreased total volume and surface area of the placental villous tissues occur with IUGR, but not with pre-eclampsia, proposed to be due to different total diffusive conductance and number of trophoblastic nuclei compared to pre-eclamptic pregnancies [34,35]. Within the villous membrane and aiding in oxygen diffusive capacity, the growth of placental trophoblasts is thought to be determined predominantly by an increased amount of nuclei [34], which contributes to overall placental size. Interestingly, women with pre-existing diabetes have shown increases in total placental volume and surface area of parenchymal tissue [36], consistent with the results of the current meta-analysis. However, women with gestational diabetes have demonstrated a greater placental weight, diameter, and thickness [36], which may suggest that stereological analyses of parenchymal tissue (including villous tissue and intervillous space) in proportion to total placental size may be a more appropriate method of assessing placental efficiency. Considering only two low quality studies in the current review investigated the potential effect of exercise training on the morphology of placental tissue, further research is warranted to assess the impact of exercise on placental structure.

Current Australian antenatal physical activity guidelines advise avoiding heavy weightlifting due to a lack of research on its safety during pregnancy [37]. Few studies have investigated the impact of resistance training on placental outcomes, although a reduction in placental weight has been found with increasing loads lifted in an occupational setting [38]. The findings of the current meta-analysis showed that combined aerobic and resistance exercise at a low-to-moderate intensity made no significant difference to placental weight when compared to no exercise or aerobic exercise only interventions. Heavy occupational lifting (≥10 kg for ≥10 times per day) during pregnancy has been associated with an increased risk of spontaneous abortion and preterm birth, suggested to be attributed to reduced uterine blood flow and increased uterine contractility from a rise in intra-abdominal pressure [39–41]. However, a positive association between maternal upper arm muscle area prior to and during pregnancy and placental system A activity has been observed in pregnant women [42]. System A activity in the placenta facilitates the uptake and transport of amino acids to the foetus, with down-regulated expression of these transporters demonstrated in IUGR pregnancies [43,44]. This may indicate that increased maternal muscle mass, commonly attributed to the performance of consistent resistance exercise, may correspond with improved placental amino acid transport capability and subsequent foetal health and development. Consistent with the Australian physical activity guidelines for pregnant women [37], low-to-moderate intensity resistance training may be beneficial for placental-foetal amino acid transport during pregnancy. However, activities that increase intra-abdominal pressure, including the use of the Valsalva manoeuvre common in heavy weightlifting, may lead to adverse placental and foetal outcomes. Further research investigating exercise modalities during pregnancy is needed to ascertain the influence that resistance training may have on placental composition and function.

Substantial villous tissue growth occurs at mid gestation through changes in oxygen tensions and expression of various growth factors, leading to increased placental angiogenesis [1,45,46]. As such, placental adaptations associated with antenatal exercise may differ throughout pregnancy. Indeed, Clapp et al. [47] showed changes in parenchymal tissue volume with exercise volumes at different timepoints during pregnancy. An increase in parenchymal volume was observed with a high to low pattern of exercise, whereby women performed 300 min of exercise per week until 20 weeks of gestation, after which the weekly volume was reduced to 100 min until delivery [47]. This was compared to women that performed exercise in a low to high pattern, with 100 min

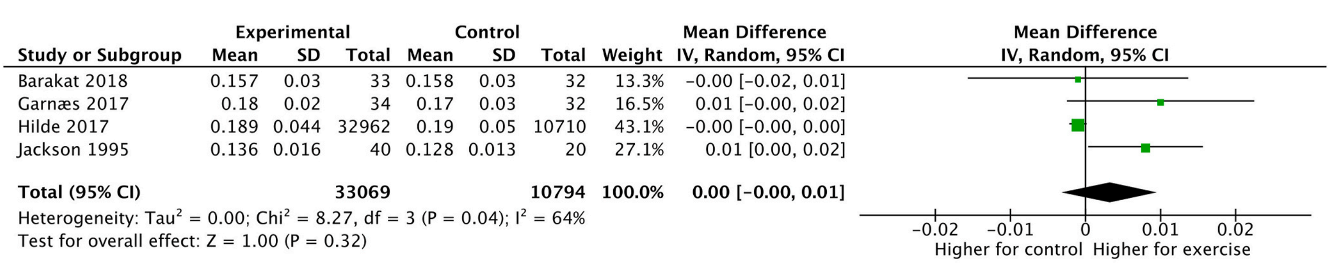


**Fig. 3.** Forest plot of the mean difference in the PWBW ratio between exercise and control groups.

of exercise per week until week 20 and then 300 min until delivery [47]. Further, women in the high to low pattern group demonstrated greater parenchymal volume compared to those that performed a consistently moderate level (maintaining 200 min per week) of physical activity during pregnancy [47]. It was proposed that the growth of intermediate villi may be stimulated by a higher level of exercise during early pregnancy, while the growth of terminal villi in later pregnancy is best stimulated by a low level of exercise [47]. Part of this increased villous growth may be dependent upon angiogenic pathways where increases in angiopoietin 1 (ANG1) mRNA has occurred with antenatal exercise [27] as well as an increased expression of placental growth factor (PlGF) and vascular endothelial growth factor (VEGF), seen in both human and animal studies [48–50]. Further, an increase in VEGF was observed with moderate, rather than low, intensity exercise compared with those that were sedentary [27]. However, while no human studies to our knowledge have investigated the effect of high-intensity interval training on the placenta, findings from a rat model found that repeated work-bouts at 85–90% of $VO_{2max}$ did not change placental weight or measures of VEGF when compared with an inactive control group [51]. These findings highlight the need for future research to investigate whether it is exercise volume (the combination of intensity, frequency, and duration) or exercise intensity (resulting in an acute stimulus to the cardiovascular system) that is responsible for functional adaptations of the placenta. Stereological examination of the placental vasculature in relation to exercise in pregnancy and the associated angiogenic mechanisms may be important in understanding what dose of exercise is beneficial for placental and foetal growth.

This systematic review and meta-analysis collated data from different study designs to begin to understand the changes in placental composition with exercise during pregnancy, however some limitations were present. Random effects models were employed to account for the large heterogeneity between exercise interventions. Causal relationships between exposures and outcomes are limited in human observational research, however, the low quality of studies included in this review warrants further high-quality evidence to determine potential associations between exercise and placental outcomes. Due to the diversity in exercise volume and adherence to the interventions reported in the included studies, exercise volume was not included in the subgroup meta-analysis. Research on the effects of higher volumes of antenatal exercise is lacking, whereby the influence on measures of placental composition remains unclear. Additionally, both subjective and objective methods were used to report exercise variables across the included studies. Gathering self-reported physical activity information from participants relies on adequate recall and appropriate knowledge of exercise intensities, which introduces the risk of overestimated or underestimated data [52]. Furthermore, the timing of delivery and the incidence of Caesarean delivery is known to impact placental weight through changes in blood volume [53,54]. Delivery mode was reported in four of the nine included studies [26,28,30,31], while the remaining studies [21,22,25,27,29] did not identify the distribution pattern of delivery modes across groups, limiting the ability to understand the influence of this confounder. In six of the seven RCTs included [26–31], physical activity prior to or following the intervention period was not investigated or reported. Further, due to the heterogeneity in the advice provided to control participants regarding physical activity throughout the intervention, it is unknown if the control group exercised during their pregnancy, and moreover, the amount of exercise that was performed. Therefore, it was not possible to ascertain to what extent participants performed exercise outside of the intervention, irrespective of the group to which they were randomised, and its effect on the placenta.

## 5. Conclusion

Women who exercised during pregnancy showed no significant difference in placental weight or the PWBW ratio, compared to women who were inactive. Although, the exercise group demonstrated an increase in parenchymal volume, represented by an increase in villous tissue, and a decrease in non-parenchymal volume of the placenta. Our findings indicate that exercise may improve placental efficiency, rather than overall size which has previously been the most common measure of placental health. Understanding how exercise during pregnancy can influence placental morphology and composition may inform appropriate exercise prescription for optimal placental health and subsequent foetal growth and development.


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## Author contributions

JK assisted in designing the study, conducted the search, extracted data, completed quality assessment, conducted statistical analyses, interpreted the data, and compiled the manuscript. VC assisted in designing the study and interpreting the data and revised the manuscript. TM assisted in interpreting the data and revised the manuscript. KB conceived and designed the study, extracted data, completed quality assessment, assisted in interpreting the data, and revised the manuscript. All authors have read and approved the manuscript for publication.

## Declaration of competing interest

None.


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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.placenta.2021.10.008.

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