

# The Effect of an Exercise Program on Maternal Health and Birth Outcomes in Sedentary Pregnant Participants with Obesity: Randomized Controlled Trial

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## ABSTRACT

HOLMES C. J., F. DINIZ-SOUSA, C. R. SIMS, L. T. JANSEN, A. MARTINEZ, A. DUPENS, D. TURNER, T. EDWARDS, J. BELLANDO, T. MASSEY-SWINDLE, E. C. DIAZ, E. BØRSHEIM, and A. ANDRES. The Effect of an Exercise Program on Maternal Health and Birth Outcomes in Sedentary Pregnant Participants with Obesity: Randomized Controlled Trial. *Med. Sci. Sports Exerc.*, Vol. 58, No. 3, pp. 559-571, 2026. **Purpose:** This study investigated the effects of a combined aerobic and resistance exercise program on maternal health and birth outcomes in pregnant people with obesity and prior sedentary lifestyle. **Methods:** Two hundred sixty-four pregnant people ( $\geq 30.0 \text{ kg/m}^2$ ) were randomly allocated to a standard-of-care group (SOC;  $n = 107$ ) or an exercise group ( $n = 157$ ). The intervention consisted of aerobic, resistance, and stretching exercises, 3× per week from the 12 wk of gestation until delivery. A submaximal cardiopulmonary exercise treadmill test was performed at 12 and 24 wk of pregnancy. Biological sample collection, body composition assessment, resting and activity energy expenditure assessment, and depression and stress evaluations were obtained at  $12.1 \pm 0.5$ ,  $24.2 \pm 0.7$ , and  $36.0 \pm 0.5$  wk of gestation. Linear mixed-effect models were used to compare maternal outcomes, while linear and logistic models were used to compare delivery outcomes. **Results:** The median compliance for exercise sessions attended from the start of exercise ( $14.0 \pm 0.8$  wk gestation) to delivery ( $38.8 \pm 1.7$  wk gestation) was 61.7%. No significant time × group interactions were found for most maternal outcomes, however, significant time × group interactions were observed in cardiorespiratory fitness outcomes, specifically in grade ( $P < 0.001$ ), heart rate ( $P = 0.003$ ), workload ( $P < 0.001$ ),  $\text{VO}_2$  ( $P < 0.001$ ) during final fitness testing stage corresponding to rating of perceived exertion of 15, and oxygen uptake efficiency slope ( $P < 0.001$ ). No significant effects were observed for other maternal health outcome measures, including gestational weight gain, systemic inflammation, and birth outcomes. **Conclusions:** Regular physical activity and participation in aerobic and resistance exercise during pregnancy are safe and effective for improving and maintaining physical fitness and activity levels in people with obesity who were previously sedentary. **Key Words:** CARDIORESPIRATORY FITNESS, GESTATIONAL WEIGHT GAIN, MATERNAL HEALTH, OBESITY, PHYSICAL ACTIVITY

Chronic diseases, such as heart disease, cancer, stroke, and diabetes, remain the leading causes of death in the United States (1). Obesity is strongly

associated with each of these diseases and continues to be a major public health issue (2,3). Between 2021 and 2023, the prevalence of obesity among all adults was 40.3% and 41.3% in women, which has raised additional health concerns for special populations, specifically in women with obesity during pregnancy (4–6). There is a greater risk of exceeding guidelines for gestational weight gain and retaining excess weight postpartum in people with excessive weight compared with people with healthy weight before pregnancy (7,8). Excessive weight at prepregnancy and higher gestational weight gain can increase the risk of maternal health complications and adverse birth outcomes, including gestational diabetes, hypertension, preeclampsia, and cesarean deliveries (C-section) (7,9–11). For these reasons, it is imperative that appropriate steps be taken to mitigate the risk of these adverse weight-related outcomes in this population.

The benefits of regular physical activity are well-documented and participation in exercise is commonly

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recommended for people in all stages of life (12). These recommendations are especially important for women of childbearing age to improve both maternal and offspring health. However, unplanned pregnancies, achieving weight loss, and maintenance of successful weight loss are challenges that must be considered as potential obstacles preventing these recommended lifestyle changes. Strategies to support those entering pregnancy with obesity and sedentary behaviors may be beneficial to those attempting to reduce excessive weight gain and increase physical activity levels (13,14). Regular physical activity and participation in various exercise modalities during pregnancy are safe and effective for improving physical fitness, even in previously sedentary people (15–19). Yet, previous reports have shown that <30% of pregnant women meet the  $\geq 150$  min of moderate-intensity aerobic physical activity per week recommended by the American College of Obstetricians and Gynecologists (ACOG) and World Health Organization (20–23).

The positive impact of physical activity and regular exercise on health and physical fitness is well-established in the general population and pregnant people; however, questions remain regarding its effects in previously sedentary people with obesity during pregnancy. Moreover, there are gaps in the literature addressing the most appropriate exercise prescription for this specific population to reduce gestational weight gain and alter cardiometabolic risk factors associated with maternal obesity. Furthermore, current recommendations do not address different exercise modalities (e.g., resistance training) and changes in exercise training variables (e.g., amount of weight lifted, number of completed repetitions, and duration of movement), which may impact the benefits gained during pregnancy for people with excessive weight and prior sedentary lifestyles (24–26). As such, the purpose of this study was to investigate the effects of a combined aerobic and resistance exercise program on maternal health and birth outcomes in pregnant women with obesity and prior sedentary lifestyles. We hypothesized that the women engaged in the exercise program would have lower gestational weight gain and markers of systemic inflammation (e.g., serum C-reactive protein [CRP]) and higher physical fitness compared with the women receiving standard obstetric care. Additionally, we hypothesized that the exercising participants would have a lower incidence of C-section relative to the standard care participants.

## MATERIALS AND METHODS

### Study Design and Participants

The expecting study is a single-center, randomized controlled trial with two parallel arms conducted at the Arkansas Children's Nutrition Center (ACNC). All experimental procedures were conducted according to the

Declaration of Helsinki and the protocol was approved by the Institutional Review Board at the University of Arkansas for Medical Sciences (IRB #202954) and registered at ClinicalTrials.gov (NCT02125149). Written informed consent was provided by each participant.

Recruitment took place in the Central Arkansas region between September 2014 and December 2023. Study advertisements, targeting pregnant women in their first trimester, were distributed across multiple locations (e.g., healthcare offices and recreational centers) using various formats (e.g., social media and radio ads). Those interested in participating in the study were screened.

Participants were required to provide a signed release from their healthcare provider to participate in exercise training. Inclusion criteria were BMI of 30–65 kg/m<sup>2</sup> at the time of enrollment, age  $\geq 18$  years, a singleton pregnancy, between 11 and 13 wk of gestation, sedentary (i.e., individuals who do not engage in purposeful physical activity and have a sedentary work activity level) and conceived without assisted fertility treatments. During the screening process, sedentary behavior was self-reported by answering questions regarding physical activity habits, including the amount of walking done in a typical day, if physical activity is tracked with any devices (e.g., pedometer, Fitbit, or similar device), and frequency, duration, and intensity of exercise sessions done per week. Exclusion criteria were preexisting medical conditions (e.g., diabetes, hypertension, thyroid disorders, and heart disease) as determined by the investigators to affect the outcomes of interest, and the use of recreational drugs, tobacco, or alcohol during pregnancy.

After obtaining informed consent, participants were allocated using computer-generated randomization into either a standard of care (SOC) or an exercise intervention (EX) group, with a greater proportion of participants randomized to the exercise group to account for variation in compliance due to the exercise regimen. Participants were assessed at  $12.1 \pm 0.5$ ,  $24.2 \pm 0.7$ , and  $36.0 \pm 0.5$  wk of pregnancy, and birth outcomes were evaluated at the postpartum 2-wk visit. Team members conducting these visits were blinded to group allocation.

### Intervention

Participants allocated to the SOC group received standard care through their obstetrician/gynecologist clinic. Participants were given physical activity recommendations for pregnancy and were instructed not to modify their dietary intake except for their normal adaptation to the pregnancy state. Finally, participants were offered 3 months of exercise facility admittance after birth to encourage engagement in physical activity postpartum.

Participants allocated to the EX group engaged in a combined aerobic and resistance exercise program that started at  $14.0 \pm 0.8$  wk of pregnancy and continued until delivery ( $38.8 \pm 1.7$  wk gestation), with three sessions per

week. The exercise program followed guidelines provided by the American College of Sports Medicine and the ACOG (12,21,27). Exercise sessions were comprised of three components: aerobic exercise, resistance exercise, and stretching. The duration of each session ranged from 30 to 45 min and followed a progressive model in the first 6 wk. From week 1 to week 6, aerobic exercise duration increased from 15 to 30 min, resistance exercise increased from 5 to 10 min, and stretching decreased from 10 to 5 min. For aerobic exercise, participants performed one or a combination of stationary bicycling, treadmill walking, and/or elliptical cross-training (Technogym Excite, Technogym, S.p.A, Italy) based on their needs and abilities. Resistance exercise workouts were full-body, circuit-based routines utilizing hydraulic resistance equipment (Technogym Easy Line, Technogym S.p.A., Italy) including seated leg press, seated leg extension, seated leg curl, chest press, seated row, shoulder press, latissimus pulldown, chest fly, biceps curl, triceps extension, and leg abductor/adductor. With hydraulic-based machines, the resistance is dynamically adjusted to match the intensity of the participant's effort, effectively increasing the load and making the movement more challenging with increased exertion. Participants completed 1–4 sets of 10–20 repetitions of each exercise. Participants were familiarized with the 6–20 Borg's rating of perceived exertion (RPE) scale (28), and exercise intensity was low to moderate, not aiming to exceed an RPE of 14. Set progression was done based on RPE responses for each exercise and as time permitted. Rest periods varied based on the participant's ability to recover between sets and exercises, and additional breaks were taken if needed. Full-body stretching was done at the close of each exercise session. In addition to RPE, progress through the intervention was tracked via heart rate (HR) monitoring, distance completed during aerobic exercise, and volume (set  $\times$  repetitions) completed during resistance exercise was recorded for each session. All exercise sessions were supervised by a trained research team member, and the participants were trained on a one-to-one basis on how to complete their exercise sessions safely. If participants were unable to attend sessions at the facility (e.g., COVID-19 pandemic restricting in-person training), at-home workouts were offered as a short-term alternative. For the at-home workouts, participants were provided resistance bands and an instructional packet describing and illustrating exercises, and a section to record time and RPE. Research trainers utilized online platforms to help supervise at-home sessions whenever possible.

### Anthropometrics and Body Composition

All measurements were obtained using standardized techniques. All anthropometric measures were taken in duplicate, or triplicate, if not within acceptable agreement. Maternal weight was measured to the nearest 0.1 kg using a tared standing digital scale (BWB-800, Tanita,

Arlington Heights, IL) while wearing a light gown, and height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (Perspectives Enterprises, Portage, MI).

Body composition assessments were performed using air displacement plethysmography (BodPod, Cosmed, Inc., Concord, CA) technology using standardized procedures adjusted for pregnancy (29). Before all body composition measurements, participants were asked to fast, except for water, for at least 3 h before the measurement and to void before the test.

### Energy Expenditure

Resting energy expenditure (REE) relative to fat-free mass (FFM), derived from  $\text{VO}_2$  ( $\text{kcal}\cdot\text{kg FFM}^{-1}\cdot\text{day}^{-1}$ ), and respiratory exchange ratio were measured by an open-circuit indirect calorimetry system (Moxus, AEI Technologies, IL). Participants were instructed not to exercise or consume caffeine for 12 h before the measurement. Participants' respiratory gas exchange was determined using a ventilated hood in a quiet, temperature-controlled room (68–71°F), with a 10-min steady state period selected following a 10-to-20-min adaptation phase.

### Blood Collection and Analysis

Up to 35 mL of blood was collected from an antecubital vein into serum vacutainers (Becton, Dickinson & Company, Franklin Lakes, NJ) following an overnight fast. Serum was isolated and stored at  $-80^\circ\text{C}$  until analyses. Serum glucose, total cholesterol, triglycerides, high-density lipoprotein, and low-density lipoprotein concentrations were measured using an RX Daytona (Randox Laboratories—US limited, Kearneysville, WV) or a Roche COBAS Integra 400 Plus (Roche Diagnostics Corp, Indianapolis, IN) clinical analyzer. Insulin, interleukin-6, CRP, leptin, and tumor necrosis factor alpha were measured using electrochemiluminescence (Meso Scale Diagnostics LLC, Rockville, MD).

### Depression and Stress

The Beck Depression Inventory Second Edition (BDI-II) was used to assess symptoms associated with depression (30). The BDI-II is a 21-item self-report questionnaire, rated on a four-point scale, which has been validated for use in pregnancy (31). Each item consists of four statements, scored 0–3, and total scores can range from 0 to 63. Participants' level of perceived stress was evaluated with Cohen's Perceived Stress Scale (32). The Perceived Stress Scale is a validated 14-item questionnaire that is scored based on participants' responses to questions that examine their perception of stressful life events and levels of experienced stress over the course of the 4 wk before the completion of the survey.

## Physical Activity

Physical activity was assessed using an accelerometer (Actical, Philips Respironics, Bend, OR) worn on the nondominant ankle using a medical band for 24 h a day over a period of 7 consecutive days at each trimester research visit. Participants were instructed to only remove the accelerometer during immersive water activities such as baths and swimming. The Actical software (version 3.1) was used to convert raw acceleration data into activity counts that were analyzed in 60-s epochs. Data from sleep periods was removed using a predefined window from 12 AM to 6 AM. Nonwear time was detected and removed using the Choi algorithm (33). Accelerometer data was only valid if it included  $\geq 10$  h per day of wear time during the awake period for  $\geq 3$  days. The number of steps per day was calculated using the accelerometer manufacturer-supplied software.

## Cardiopulmonary Exercise Testing

To assess aerobic fitness, participants performed a submaximal cardiopulmonary exercise test (CPET) at 12 and 24 wk of gestation, but not at 36 wk due to safety reasons, as advanced pregnancy is a relative contraindication for cardiopulmonary exercise testing (34). Before the 24-wk visit, EX group participants refrained from exercise for  $\geq 48$  h. Following a 3-min warm-up, the CPET began with walking on a treadmill (Trackmaster, Full Vision, Inc., Newton, KS) at 2.5 mph and 0% grade. Every 2 min, the incline increased by 2% while the speed remained constant. If the participant reached 12% incline, the speed would steadily increase while the incline remained constant. During the test, participants were instructed to not hold onto the handrails unless immediate support was needed to maintain balance. Once balance was reestablished, participants were asked to continue testing without handrail support. At the end of each stage, participants were asked to rate their perceived exertion using the 6–20 Borg scale (28). Once a participant reached an RPE of 15, a cool-down was initiated, marking the end of the test. During the entire test, participants wore an indirect calorimetry facemask to sample and measure breath composition using a metabolic cart (Medgraphics Ultima PFX system, MGC Diagnostics Corporation, St. Paul, MN). Participants also wore an HR monitor to assess exercise HR (Mortara 12-Lead ECG, MGC Diagnostics Corporation, St. Paul, MN). Data from the last 30 s of the final completed stage were used to obtain the average HR (beats/min) and oxygen consumption ( $\text{VO}_2$ ; mL  $\text{O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) at RPE-15. The oxygen uptake efficiency slope (OUES) was also calculated using the last 30 s of each completed stage, based on the slope of the linear relationship between  $\text{VO}_2$  and the logarithm of ventilation (VE) (35).

## Birth Outcomes and Adverse Events

Birth outcomes (delivery method, birth weight, and length) were self-reported by the participant's mother at a 2-wk postpartum visit. The Z-scores were calculated using the World Health Organization Growth Reference Standards to generate length-for-age Z, weight-for-age Z, and weight-for-length Z (36).

## Adverse Events

All adverse events were reported according to institutional policies. Each recorded adverse event was categorized into the following: miscarriage, premature delivery or emergency C-section, pregnancy-related general health concern (e.g., preeclampsia, pelvic girdle pain, gestational diabetes, and gestational hypertension), mental health concern (i.e., specific criteria met on the BDI-II or diagnosis of depression or other mental health disorders), and reactions to study procedures. Reactions to study procedures included feeling lightheaded, nauseous, or discomfort/pain during or following a CPET and/or blood draw.

## Statistical Analysis

Continuous variables are reported as mean and standard deviation ( $M \pm SD$ ), and categorical variables are reported as counts and percentages. Statistical analysis was completed using the R programming language (version 4.3.1, R Foundation, Vienna, Austria) (37). Descriptive statistics were summarized using the arsenal package (38). A  $P < 0.05$  was considered statistically significant. Following an intention-to-treat framework, linear mixed-effect models were used to compare maternal outcomes throughout pregnancy between the EX and SOC groups, while linear and logistic models were used to compare delivery outcomes between the two groups. The sample size and power calculation were based on the main research project purpose, which focused on infant body composition and risk of obesity at 24 months, and not on the primary outcomes of the present manuscript. We anticipated that 30% of enrolled participants would not complete the study (loss to follow-up and dropped), and 20% of participants would not comply with the exercise regimen. Therefore, we planned to enroll 264 participants to achieve approximately 150 infants at 24 months of age (75 per group). Calculations were based on analysis of longitudinal data, assuming a sample size of 75 infants per group ( $n = 150$ ), four repeated measurements (0.5, 6, 12, and 24 months of offspring follow-up), 80% power, and a significance probability of 5% ( $\alpha = 0.05$ ). There was sufficient statistical power to detect small to medium effect sizes, even with a reduced sample size of 50/group.

## RESULTS

### Participants

Figure 1 depicts participants' screening, enrollment, and retention during the study. Of the 1652 pregnant women who contacted our research facility, 1147 were excluded because of inclusion or exclusion criteria. Of the 505 eligible pregnant women, 264 pregnant women were enrolled, 107 were allocated to the SOC group and 157 to the EX group. In the SOC group, dropout rates were 15.9% ( $n = 17$ ) between 12 and 24 wk, with no additional dropouts between 24 and 36 wk or between 36 wk and birth. In the EX group, dropout rates were 17.2% ( $n = 27$ ) from 12 to 24 wk, 4.5% ( $n = 7$ ) from 24 to 36 wk, and 1.3% ( $n = 2$ ) from 36 wk to birth.

Maternal baseline characteristics for both groups are shown in Table 1. There were no significant differences in baseline characteristics between the SOC and EX groups, except for marital status with 70.8% of participants in the SOC group being married or cohabiting compared with 83.4% in the EX group ( $P = 0.014$ ). The overall maternal age at the time of randomization was  $29.5 \pm 5.0$  years. Additionally, 42.2%, 31.9%, and 25.9% of the participants were classified with obesity class I, II, and III, respectively. The sample was primarily composed of White (63.6%) and African American (33.7%) participants, with

the majority (95.8%) being non-Hispanic. Most of the participants had partial or full college education (66.2%). Regarding prior live births, 27.3% had no prior live births, 37.9% had one prior live birth, 19.3% had two prior live births, and 15.5% had three or more prior live births.

### Adverse Events and Compliance

No adverse events occurred during or immediately following the exercise sessions during the intervention. Over the duration of the study independent from the intervention exercise sessions, 55 adverse events were reported (SOC = 26, EX = 29) falling into one of the previously described categories: miscarriage (SOC = 3, EX = 2), pregnancy-related general health concern (SOC = 15, EX = 10), reaction to CPET (SOC = 7, EX = 12), mental health concern (SOC = 0, EX = 2), reaction to blood draw (SOC = 0, EX = 1), bleeding around blood draw site (SOC = 0, EX = 1), or premature delivery/emergency C-section (SOC = 1, EX = 1). The 55 adverse events occurred in 45 participants (SOC = 20, EX = 25) or 17.0% (SOC = 18.7%, EX = 15.9%) of the total number of participants enrolled. No statistically significant difference was found between the number of adverse events between the SOC and EX groups ( $P = 0.23$ ).

The median compliance for exercise sessions attended from the start of exercise ( $14.0 \pm 0.8$  wk gestation) to

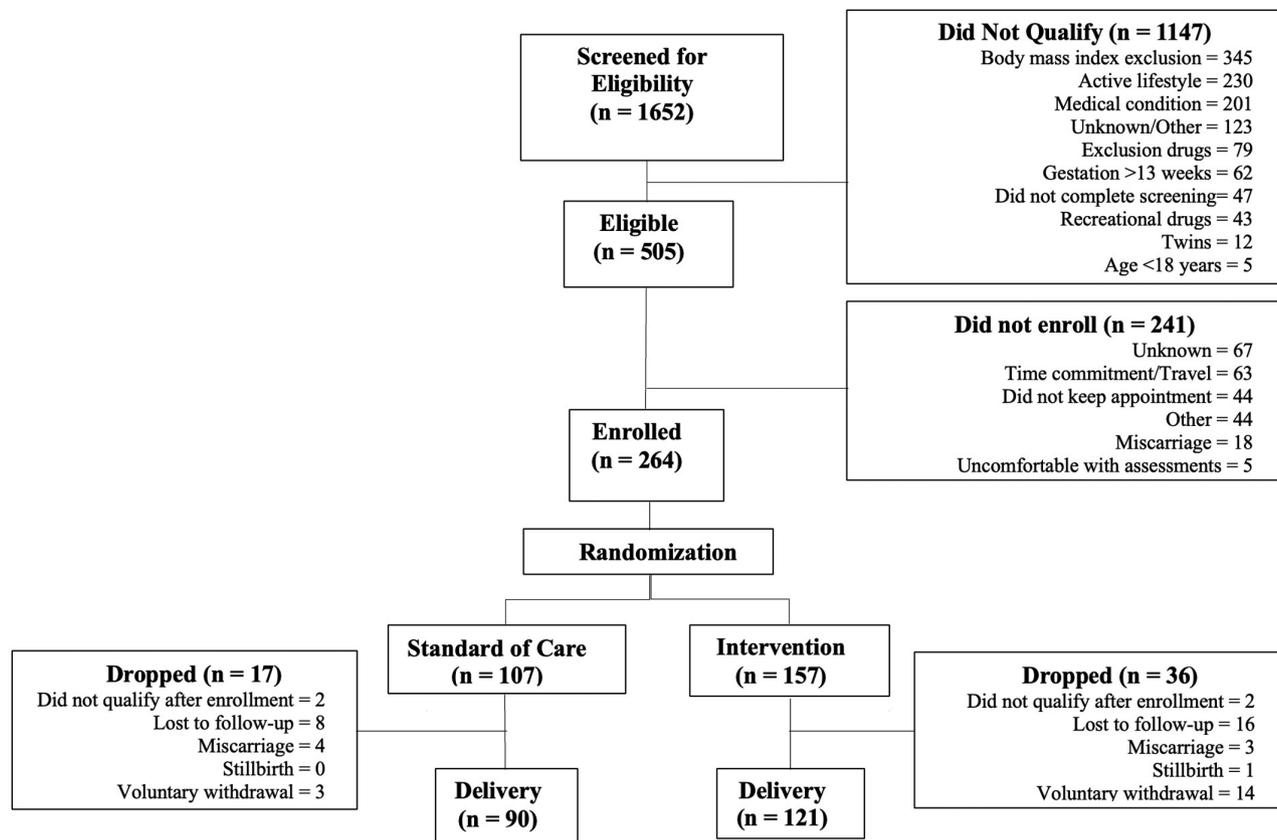


FIGURE 1.—Cohort flow diagram.

TABLE 1. Maternal baseline characteristics.

Characteristics	Total (n = 264)	SOC (n = 107)	EX (n = 157)	P-value
Maternal age (years)	29.5 ± 5.0	29.1 ± 4.9	29.8 ± 5.0	0.302
Height (cm)	163.7 ± 6.4	163.2 ± 6.2	164 ± 6.6	0.310
Body mass index (kg·m <sup>-2</sup> )	37.0 ± 5.6	37.6 ± 6.6	36.6 ± 4.8	0.131
Obesity category (%)				
Class I (BMI: 30.0–34.9 kg·m <sup>-2</sup> )	111 (42.2%)	43 (40.6%)	68 (43.3%)	0.405
Class II (BMI: 35.0–39.9 kg·m <sup>-2</sup> )	84 (31.9%)	31 (29.2%)	53 (33.8%)	
Class III (BMI: ≥40.0 kg·m <sup>-2</sup> )	68 (25.9%)	32 (30.2%)	36 (22.9%)	
Race (%)				
African American	89 (33.7%)	40 (37.4%)	49 (31.2%)	0.563
White	168 (63.6%)	64 (59.8%)	104 (66.2%)	
Other	7 (2.7%)	3 (2.8%)	4 (2.5%)	
Ethnicity (%)				
Hispanic	11 (4.2%)	4 (3.7%)	7 (4.5%)	0.774
Non-Hispanic	253 (95.8%)	103 (96.3%)	150 (95.5%)	
Education (%)				
High school education or less	43 (16.3%)	19 (17.9%)	24 (15.3%)	0.850
Partial or full college education	174 (66.2%)	69 (65.1%)	105 (66.9%)	
Partial or full graduate education	46 (17.5%)	18 (17.0%)	28 (17.8%)	
Marital status (%)				
Married/cohabitating	206 (78.3%)	75 (70.8%)	131 (83.4%)	0.014
Not Married/Cohabitating	57 (21.7%)	31 (29.2%)	26 (16.6%)	
Previous children (%)				
0	72 (27.3%)	27 (25.2%)	45 (28.7%)	0.939
1	100 (37.9%)	39 (36.4%)	61 (38.9%)	
2	51 (19.3%)	24 (22.4%)	27 (17.2%)	
≥3	41 (15.5%)	17 (15.9%)	24 (15.3%)	

Data: mean ± standard deviation or n (%).

EX, exercise intervention; SOC, standard care group.

delivery (38.8 ± 1.7 wk gestation) was 61.7% (median session attendance 75.0 [71.3, 77.0]). From the start of exercise to the 24-wk visit (24.2 ± 0.7 wk gestation), compliance was 78.1% (median session attendance 30.0 [28.0, 32.0]). From the 24-wk visit to the 36-wk visit (36.0 ± 0.5 wk gestation), compliance was 64.8% (median session attendance 36.0 [34.0, 36.0]). From the 36-wk visit to delivery, compliance was 26.1% (median session attendance 9.0 [8.0, 12.0]). Between weeks 12 and 24, 7.3% (*n* = 9) attended less than <33.3% of the sessions, 22.0% (*n* = 27) attended between 33.3% and 66.5%, and 70.7% (*n* = 87) attended ≥66.6% or more of the sessions. Between weeks 24 and 36, 23.1% (*n* = 24) attended <33.3% of the sessions, 27.9% (*n* = 29) attended between 33.3% and 66.5%, and 49.0% (*n* = 51) attended ≥66.6% or more of the sessions.

### Exercise Intervention

The first and last exercise sessions took place at 14.0 ± 0.8 and 31.5 ± 8.3 wk of pregnancy, respectively (range: 12.6–40.0 wk). When using the treadmill for the aerobic exercise portion of the intervention, the EX participants completed 0.6 ± 0.2 mi per session in 14.5 ± 4.1 min at a speed and grade of 2.5 ± 0.1 mph and 1.7 ± 0.5%, respectively. During treadmill-based exercise, the average HR was 129.0 ± 9.8 bpm (67.9 ± 5.0% of age-predicted max [220-age]) with a reported RPE

of 10.6 ± 1.8. When using the elliptical, a distance of 0.3 ± 0.2 mi per session was completed in 9.2 ± 3.9 min at a speed of 87.7 ± 7.6 rpm at a resistance level of 1.2 ± 0.4. Average exercise HR was 136.9 ± 11.5 bpm (69.6 ± 14.5%) with a reported RPE of 11.2 ± 2.1. When using the recumbent bike, the participants completed 1.5 ± 0.6 mi per session in 7.9 ± 2.8 min at a speed of 61.2 ± 8.8 rpm at a resistance level of 1.6 ± 0.1. While on the bike, HR was 119.8 ± 9.5 bpm (63.0 ± 5.1%) with a reported RPE of 9.7 ± 1.8. Weekly averages of aerobic exercise variables can be seen in Supplemental Table 1, Supplemental Digital Content, <https://links.lww.com/MSS/D320>. For the resistance exercise component of the intervention, the EX group completed 1.9 ± 0.4 sets per exercise per session. During each set of an exercise, 15.7 ± 1.7 repetitions were performed, equating to a volume of 29.0 ± 6.7 repetitions per exercise per session. Participant-reported RPE was 10.9 ± 1.7. Weekly averages of resistance exercise volume and RPE can be seen in Supplemental Figure 1, Supplemental Digital Content, <https://links.lww.com/MSS/D320>.

### Maternal Outcomes

Table 2 displays the maternal outcomes at 12.1 ± 0.5, 24.2 ± 0.7, and 36.0 ± 0.5 wk during pregnancy in the EX and SOC groups. No significant time × group interactions were found (*P* > 0.05) for most maternal outcomes,

TABLE 2. Maternal outcomes at 12 wk and changes from 12 to 24, and 12 to 36 wk of pregnancy in the exercise intervention (EX) and standard-of-care (SOC) groups.

Outcomes	Group	12 wk	Δ 24 wk	Δ 36 wk	P-Interaction
<b>Body composition</b>					
Body mass index (kg·m <sup>-2</sup> )	SOC	37.6 (6.6)	1.3 (1.1)	3.1 (2.1)	0.944
	EX	36.6 (4.8)	1.3 (1.2)	3.2 (2.1)	
Fat mass index (kg·m <sup>-2</sup> )	SOC	18.4 (5.3)	0.3 (1.2)	0.5 (2.1)	0.950
	EX	17.5 (3.7)	0.3 (1.2)	0.5 (2.1)	
Fat-free mass index (kg·m <sup>-2</sup> )	SOC	19.2 (2.4)	1.0 (0.9)	2.7 (1.3)	0.973
	EX	18.9 (1.9)	1.0 (0.9)	2.8 (1.1)	
<b>Blood pressure</b>					
Systolic blood pressure (mm Hg)	SOC	108.3 (10.2)	-1.0 (10.1)	1.1 (12.2)	0.642
	EX	109.5 (10.2)	-2.6 (11.3)	1.7 (11.9)	
Diastolic blood pressure (mm Hg)	SOC	72.7 (8.0)	-2.7 (6.7)	1.5 (8.6)	0.280
	EX	73.4 (8.3)	-3.6 (7.6)	1.3 (9.5)	
<b>Lipid profile</b>					
Cholesterol (mmol·L <sup>-1</sup> )	SOC	4.9 (0.89)	0.96 (0.81)	1.2 (1.10)	0.942
	EX	4.9 (0.80)	0.91 (0.76)	1.2 (1.10)	
HDL (mmol·L <sup>-1</sup> )	SOC	1.6 (0.34)	0.23 (0.22)	0.15 (0.27)	0.088
	EX	1.6 (0.33)	0.24 (0.26)	0.07 (0.29)	
LDL (mmol·L <sup>-1</sup> )	SOC	3.0 (0.85)	0.73 (0.79)	1.2 (1.13)	0.445
	EX	3.0 (0.73)	0.61 (0.64)	1.1 (1.12)	
Triglycerides (mmol·L <sup>-1</sup> )	SOC	1.2 (0.43)	0.53 (0.42)	1.1 (0.71)	0.268
	EX	1.3 (0.47)	0.63 (0.50)	1.3 (0.69)	
<b>Glucose-insulin profile</b>					
Glucose (mmol·L <sup>-1</sup> )	SOC	4.9 (0.47)	-0.02 (0.49)	-0.03 (0.54)	0.907
	EX	4.9 (0.45)	0.02 (0.57)	-0.02 (0.64)	
Insulin (pmol·L <sup>-1</sup> )	SOC	103.5 (65.3)	16.0 (42.8)	43.6 (65.4)	0.275
	EX	100.6 (57.6)	29.8 (50.4)	51.6 (85.2)	
<b>Inflammatory profile</b>					
CRP (mg·L <sup>-1</sup> )	SOC	19.5 (17.8)	0.9 (16.8)	-5.6 (15.4)	0.302
	EX	19.5 (14.6)	-1.2 (9.5)	-4.7 (12.4)	
IFN-γ (pg·mL <sup>-1</sup> )	SOC	3.4 (4.1)	2.9 (12.7)	0.4 (5.2)	0.193
	EX	4.4 (7.0)	-1.0 (8.3)	-0.3 (10.4)	
IL-6 (pg·mL <sup>-1</sup> )	SOC	0.70 (0.36)	0.1 (0.3)	0.2 (0.4)	0.392
	EX	0.74 (0.47)	0.1 (0.4)	0.3 (0.4)	
Leptin (ng·mL <sup>-1</sup> )	SOC	63.5 (33.2)	7.2 (20.9)	6.6 (32.0)	0.808
	EX	56.5 (27.9)	8.7 (23.6)	6.6 (27.7)	
TNF-α (pg·mL <sup>-1</sup> )	SOC	1.0 (0.36)	0.0 (0.4)	0.1 (0.3)	0.862
	EX	1.0 (0.52)	0.0 (0.6)	0.2 (0.4)	
<b>Energy expenditure</b>					
REE/FFM (kcal·kg FFM <sup>-1</sup> ·day <sup>-1</sup> )	SOC	37.6 (5.5)	-0.1 (5.2)	0.1 (5.9)	0.728
	EX	37.6 (5.3)	0.5 (6.2)	0.6 (6.2)	
RER	SOC	0.80 (0.06)	0.0 (0.1)	0.0 (0.1)	0.682
	EX	0.79 (0.07)	0.0 (0.1)	0.0 (0.1)	
<b>Depression and stress profile</b>					
BDI	SOC	8.8 (5.5)	—	1.4 (6.3)	0.223
	EX	9.1 (6.4)	—	0.2 (5.5)	
PSS	SOC	19.5 (7.6)	-0.4 (7.5)	-0.6 (6.7)	0.204
	EX	18.9 (7.3)	0.3 (7.0)	0.9 (6.4)	
<b>Total energy consumption</b>					
Energy intake (kcal·day <sup>-1</sup> )	SOC	1937.9 (642.5)	236.7 (572.6)	205.7 (696.8)	0.545
	EX	1941.0 (568.6)	108.4 (572.4)	127.9 (541.9)	
<b>Physical activity levels</b>					
Steps (n·day <sup>-1</sup> )	SOC	6129.5 (1934.7)	-98.1 (1941)	-889.8 (1889.3)	0.386
	EX	6718.8 (2799.8)	47.5 (2599.2)	-592.9 (2768.9)	
<b>Cardiorespiratory fitness</b>					
Perceived exertion (RPE) at the end of the test	SOC	15.2 (1.1)	0.2 (1.4)	—	0.054
	EX	15.3 (1.1)	-0.2 (1.6)	—	
Grade (%) at RPE-15	SOC	7.7 (2.7)	-0.8 (2.5)	—	<0.001
	EX	7.6 (2.3)	1.1 (2.5)	—	
Heart rate (BPM) at RPE-15	SOC	160.6 (14.5)	-3.7 (17.0)	—	0.003
	EX	157.7 (15.0)	1.8 (12.7)	—	
Workload (W) at RPE-15	SOC	82.1 (31.0)	-6.0 (29.9)	—	<0.001
	EX	80.5 (26.4)	14.7 (30.6)	—	
VO <sub>2</sub> (mL O <sub>2</sub> ·kg <sup>-1</sup> ·min <sup>-1</sup> ) at RPE-15	SOC	16.7 (3.1)	-1.6 (3.1)	—	<0.001
	EX	16.3 (2.9)	0.6 (2.6)	—	
OUES	SOC	2174.3 (487.8)	-83.3 (458.7)	—	<0.001
	EX	2167.9 (489.1)	171.2 (449.0)	—	

Data: mean (standard deviation).

BDI, beck depression inventory; BPM, beats per minute; EX, exercise intervention; FFM, fat-free mass; HDL, high-density lipoprotein; IL-6, interleukin-6; LDL, low-density lipoprotein; OUES, oxygen uptake efficiency slope; PSS, perceived stress scale; REE, resting energy expenditure; RER, respiratory exchange ratio; RPE-15, rate of perceived exertion of 15, corresponding to the last stage of the submaximal cardiorespiratory fitness test; SOC, standard of care; TNF-α, tumor necrosis factor alpha.

including gestational weight gain, body composition, blood pressure, serum lipid panel, serum glucose-insulin profile, serum inflammatory markers, REE, respiratory exchange ratio, depression and stress scores, and estimates of total energy consumption. However, significant time  $\times$  group interactions were observed in cardiorespiratory fitness outcomes, specifically in grade ( $P < 0.001$ ), HR ( $P = 0.003$ ), workload ( $P < 0.001$ ),  $\text{VO}_2$  ( $P < 0.001$ ) during final fitness testing stage corresponding to RPE-15, and OUES ( $P < 0.001$ ). Compared with the SOC group at 24 wk, the EX group achieved a higher grade ( $\Delta 2.2\%$ , 95% CI: 1.5–2.8,  $P < 0.001$ ), greater workload ( $\Delta 23.9$  watts, 95% CI: 15.9–32.0,  $P < 0.001$ ), and greater  $\text{VO}_2$  ( $\Delta 2.1 \text{ mL O}_2 \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ , 95% CI: 1.3–3.0,  $P < 0.001$ ), while HR was not significantly different between groups ( $\Delta 4.3$  bpm, 95% CI:  $-0.1$  to 8.8,  $P = 0.057$ ) during the last stage of testing. In addition to these outcomes, the benefits of exercise participation on cardiorespiratory fitness were also reflected in OUES, with the EX group achieving a significantly higher value compared with the SOC group ( $\Delta 258.3$ , 95% CI: 104.9–411.6,  $P = 0.001$ ) (Fig. 2).

## Exercise Adherence Subgroup Analysis

Besides assessing effectiveness (via intention-to-treat analysis), exercise efficacy was evaluated based on adherence to the intervention. An analysis of exercise adherence revealed several significant time  $\times$  group interactions in cardiorespiratory fitness outcomes, namely in grade ( $P < 0.001$ ), HR ( $P = 0.007$ ), work ( $P < 0.001$ ),  $\text{VO}_2$  ( $P < 0.001$ ) during the final stage of fitness testing corresponding to RPE-15, and OUES ( $P < 0.001$ ). Compared with the SOC group at 24 wk, participants with  $\geq 66.6\%$  training attendance achieved a higher final grade ( $\Delta 2.4\%$ , 95% CI: 1.7–3.1,  $P < 0.001$ ), greater workload ( $\Delta 27.8$  watts, 95% CI: 19.2–36.3,  $P < 0.001$ ), higher  $\text{VO}_2$  ( $\Delta 2.2 \text{ mL O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ , 95% CI: 1.4–3.1,  $P < 0.001$ ), and higher OUES ( $\Delta 315.9$ , 95% CI: 161.7–470.1,  $P = 0.001$ ). Participants with  $\geq 66.6\%$  training attendance also achieved a higher final grade ( $\Delta 2.7$ , 95% CI: 0.8–4.6,  $P = 0.032$ ) and greater work at the final stage ( $\Delta 40.9$  watts, 95% CI: 18.7–63.2,  $P = 0.002$ ) compared with those with  $< 33.3\%$  attendance. A significant time  $\times$  group interaction was also found for physical activity levels ( $P =$

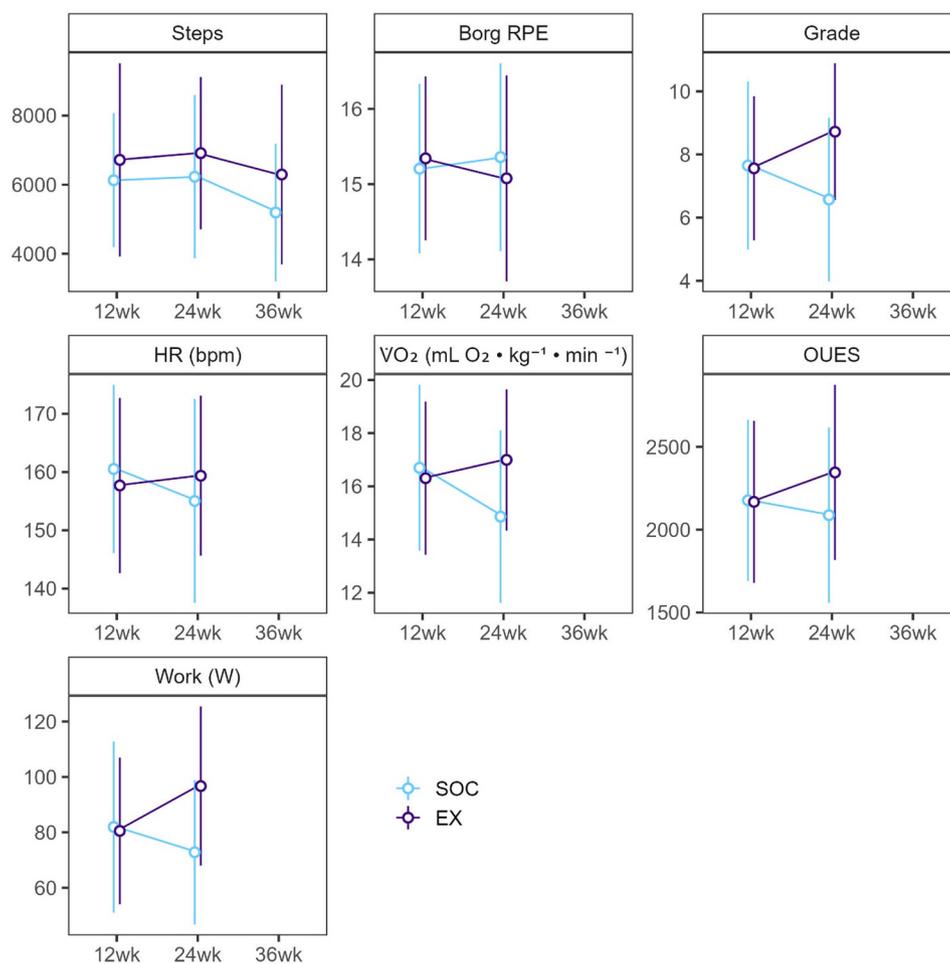


FIGURE 2.—Changes in cardiorespiratory fitness metrics and step count from 12-wk visit to 24-wk visit. EX, exercise group; HR, heart rate; OUES, oxygen uptake efficiency slope; RPE, rating of perceived exertion; SOC, stand-of-care group;  $\text{VO}_2$ , oxygen consumption.

0.039). Participants with  $\geq 66.6\%$  training attendance were also more physically active than the SOC group at 24 wk ( $\Delta 1109.4$  steps, 95% CI: 354.0–1864.8,  $P = 0.025$ ). A significant time  $\times$  group interaction was found for leptin at 36 wk ( $P = 0.023$ ), but this difference did not remain significant after multiple comparison correction. No additional significant time  $\times$  group interactions were found in the remaining maternal outcomes or in any birth outcomes. Analyses using recursive partitioning based on  $\text{VO}_2$  at 24 wk revealed similar effects on maternal and birth outcomes to those observed in the analysis reported above.

### Birth Outcomes

Table 3 displays the birth outcomes in the EX and SOC groups. Gestational age at birth was similar between groups (0.1 wk, 95% CI:  $-0.4$  to  $0.6$ ,  $P = 0.831$ ). No differences were observed in the delivery methods ( $P > 0.05$ ) between the two groups. There were no differences between groups in birth length (0.5 cm, 95% CI:  $-0.3$  to  $1.4$ ,  $P = 0.219$ ) or birth weight (0.1 kg, 95% CI:  $0.0$ – $0.3$ ,  $P = 0.163$ ). Similarly, there were no differences in birth length-for-age Z-scores (0.3, 95% CI:  $-0.2$  to  $0.7$ ,  $P = 0.253$ ), birth weight-for-age Z-scores (0.2, 95% CI:  $-0.1$  to  $0.6$ ,  $P = 0.206$ ), and birth weight-for-length Z-scores (0.0, 95% CI:  $-0.4$  to  $0.5$ ,  $P = 0.840$ ).

### DISCUSSION

This study aimed to investigate the effects of a combined aerobic and resistance exercise program on maternal health markers and birth outcomes in previously sedentary, pregnant women with obesity. We hypothesized that the intervention group would have lower gestational weight gain and systemic inflammation, higher levels of physical fitness, and lower incidence of C-section compared with participants in the SOC group. Results indicate that exercise improved cardiorespiratory

fitness during pregnancy compared with standard obstetric care. Conversely, both groups demonstrated similar trends without significant differences in all other maternal health measures, adverse events, and birth outcome measures.

Cardiorespiratory fitness is a well-established predictor of overall health (39), and emerging evidence highlights its potential relevance to pregnancy-specific outcomes. In addition to the improvement in aerobic capacity among the intervention group, a clear dose-response relationship was observed, with participants who had higher attendance rates achieving greater improvements in physical fitness. While the positive effects of our intervention on aerobic capacity were not reflected in other maternal or birth outcomes, previous studies have associated physical fitness during pregnancy with cardiometabolic markers (e.g., glucose and lipid metabolism) (40), oxygen saturation in the arterial umbilical cord (41), labor duration (42), and C-section risk (41). Despite the potential influence of cardiorespiratory fitness on pregnancy outcomes, the data supporting an association between prenatal EX and increased aerobic capacity remains limited and of low certainty of evidence (17). There is a scarcity of high-quality studies adequately assessing cardiorespiratory fitness (43), many of which rely on predicted equations based on exercise-protocol HR responses (43,44). In contrast, our findings on the effects of exercise on aerobic capacity appear robust, as improvements were observed not only in outcomes based on perceived-effort threshold criteria but also in external workload and efficiency measures (e.g., OUES) (35,45). Studies using similar approaches, such as measuring oxygen consumption at the first ventilatory threshold, have consistently demonstrated benefits in cardiorespiratory fitness among pregnant people participating in EX compared with SOC (46–48). Apparent discrepancies in the literature regarding the effects of exercise on objectively measured cardiorespiratory fitness outcomes (e.g.,  $\text{VO}_2$ ) may stem from

TABLE 3. Birth outcomes in the exercise intervention and standard-of-care groups.

Outcomes	SOC (n = 90)	EX (n = 121)	Mean Difference (95% CI)	P-Value
Gestational weight gain (kg) <sup>a</sup>	8.4 (5.5)	8.7 (5.7)	0.3 (–1.3 to 2.0)	0.651
Gestational age (weeks)	38.8 (2.0)	38.8 (1.7)	0.1 (–0.4 to 0.6)	0.831
Birth length (cm)	50.0 (3.1)	50.5 (2.9)	0.5 (–0.3 to 1.4)	0.219
Birth length-for-age Z	0.2 (1.7)	0.5 (1.5)	0.3 (–0.2 to 0.7)	0.253
Birth weight (kg)	3.3 (0.6)	3.4 (0.6)	0.1 (0.0 to 0.3)	0.163
Birth weight-for-age Z	0.0 (1.3)	0.2 (1.2)	0.2 (–0.1 to 0.6)	0.206
Birth weight-for-length Z	–0.2 (1.4)	–0.2 (1.5)	0.0 (–0.4 to 0.5)	0.840
Delivery Method			Odds Ratio (95% CI) <sup>b</sup>	
Spontaneous vaginal delivery	30 (33.3%)	49 (40.5%)	—	
Induced vaginal delivery	16 (17.8%)	24 (19.8%)	0.9 (0.4 to 2.0)	0.830
Cesarean section delivery	26 (28.9%)	31 (25.6%)	0.7 (0.4 to 1.5)	0.372
Emergency cesarean section delivery	18 (20.0%)	17 (14.0%)	0.6 (0.3 to 1.3)	0.182

Data: mean (standard deviation).

<sup>a</sup>From the 36-wk gestation assessment visit.

<sup>b</sup>Spontaneous vaginal delivery used as reference.

EX, exercise intervention; SOC, standard of care.

methodological issues (49–51), particularly the reliance on HR thresholds as end criteria for identifying cardiorespiratory fitness outcomes, given that both blunted and normal HR responses can occur during pregnancy (21,44).

Given the intersection of two proinflammatory states: pregnancy (52) and obesity (53), we hypothesized that systemic inflammation in our study population would be generally upregulated, with EX participants eliciting lower levels of inflammatory markers compared with SOC. Observational studies have shown that physically active pregnant people, both with normal weight and obesity, tend to exhibit lower levels of inflammation (e.g., CRP) (54), though this effect may primarily result from higher physical activity intensities (55). Garnaes et al. (56) conducted an RCT in pregnant people with obesity involving a supervised exercise program of 60-min sessions 3×/week at moderate intensities (RPE: 12–15), consisting of a 35-min treadmill walk and 25-min of strengthening exercises, complemented by additional home exercises. Their findings showed no differences in inflammatory markers compared with SOC, aligning with the results observed in our study. The restriction on high exercise intensities (e.g., vigorous) during pregnancy may partly explain the absence of effects, as evidence from the general population with overweight and obesity suggests that high-intensity exercise more effectively reduces inflammation (21,57). Furthermore, pregnancy-mediated shifts in inflammatory profiles may neutralize any effects mediated by physical activity (58). The lack of differences in lipid profiles observed in our study and similar RCTs (56,59) is also not surprising, given that only modest effects of exercise are expected in the general population, even with more demanding prescription recommendations (e.g., ≥5 days of exercise per week) (60).

Our study did not find significant exercise effects on other outcome measures including body composition, blood pressure, depression scores, or stress levels. Regarding body composition changes, this aligns with evidence suggesting that less than 150 min of moderate activity per week has a limited impact on weight control in individuals with obesity (27). This may also be attributed to the absence of group differences in energy consumption and physical activity levels via step count during pregnancy. Further analyses revealed that participants with higher exercise attendance demonstrated increased physical activity levels. Yet, this did not translate into meaningful changes in body composition or other relevant health outcomes assessed, highlighting the need for future research into the dose-response relationship among the current study population. The lack of significant change in REE and no shift toward fat oxidation-based energy metabolism in the EX group compared with the SOC may further explain these findings (61). The similar trends in blood pressure over time between groups are consistent with previous studies in pregnant people with excess weight, which also found no

differences between exercise and control groups (62,63). With respect to depression, although evidence from the general pregnant population suggests that moderate positive effects may be observed when participants engage in at least 644 MET-minutes per week of moderate-to-vigorous intensity exercise (e.g., 150 min of moderate-intensity activity) (64), trials focusing on participants with overweight or obesity (65,66), including our own study, have consistently shown no effect on depressive symptoms. There is also evidence from analogous studies also showing no improvements induced by exercise on quality of life and well-being in pregnant people with excess weight (49,65). Finally, in addition to the maternal health outcomes, there is no definitive consensus on the effects of prenatal exercise on C-section delivery rates, with other studies showing no influence, similar to our results (19).

### Strengths and Limitations

This study has several strengths worth highlighting. First and foremost, a randomized controlled trial design was utilized to provide a comparative analysis of the effects of exercise relative to standard obstetric care. The study also boasted a large sample size in a higher risk special population. Importantly, our study focuses on enrolling and randomizing pregnant participants with obesity and prior sedentary lifestyles enhances the external validity and clinical relevance of our findings while addressing gaps in the current literature. Even with this large sample size in this special population, no adverse events occurred during or immediately following exercise training sessions. These results further demonstrate the safety of resistance exercise participation in pregnant women, even if the individual was considered sedentary before starting. Another strength of the current study includes the duration of the intervention ( $26.0 \pm 0.8$  wk). Finally, the number of selected outcome measures displays a comprehensive assessment of maternal health outcomes related to common clinical issues seen during pregnancy.

Despite its strengths, the current study is not without limitations. A major point of concern when it comes to long-term EX is unreported or poor compliance among RCTs (17,18). Though the compliance rate of the current study falls in line with previous studies (50,56,67–69), there was a stark contrast between the first 12 wk of the intervention compared with the remaining weeks before delivery. Seneviratne et al. (49) reported a low compliance of 33% and observed a steady decline in adherence as pregnancies progressed. The drop-off may be attributed to the physical toll and/or psychological stress accumulated in the later stages of pregnancy. Additionally, because all study visits took place at the ACNC, travel distance may have impacted the participants' ability to attend regularly. Exercise prescription guidelines by

ACOG recommend that for special populations, such as pregnant people with obesity, exercise training should start with low-intensity, short periods of exercise, and gradually increase to more moderate intensities based on the percentage of age-predicted max HR (i.e., 60%–80%) or RPE (i.e., 12–14) (21). Though the target exercise HR intensity was met during aerobic exercise, the resulting RPE-based intensity for the resistance exercise phase fell below the 12–14 range, being categorized between “light” and “very light.” The drop in RPE below the 12–14 range may be attributed to several reasons including the resistance exercise equipment used, additional unplanned rest periods needed, the participants’ lack of training experience, and the subjective nature of RPE itself. To manipulate the amount of resistance the participant experiences during an exercise, the hydraulic resistance equipment adjusts based on the force and power being produced by the individual. Despite coaching cues being given by the trainers, participants may not have given the proper physical exertion during each exercise to elicit greater resistance from the hydraulic equipment leading to the perception of lesser intensity and a lower RPE score. Participants were also allowed short rest periods as needed throughout the resistance training portion of the sessions. This additional recovery within the exercise bout before selecting an RPE score may have affected its reporting. Future research should look to incorporate more individualized exercise tailoring and utilize higher intensities, particularly with resistance exercise using different types of equipment, to potentially stimulate greater cardiometabolic effects in pregnant people with obesity.

## CONCLUSIONS

In summary, the current study demonstrates that a combined aerobic and resistance exercise program is safe and effective in maintaining and improving cardiorespiratory fitness and physical activity levels in previously sedentary, pregnant women with obesity. Consistent with our initial hypothesis, the intervention improved cardiorespiratory fitness. However, no significant effects were observed for other maternal health outcome measures, including gestational weight gain, systemic inflammation, and birth outcomes, such as delivery method, contrary to our hypotheses. Insights gained from this investigation highlight the need for future research to explore a potential dose-response relationship between compliance in combined aerobic and resistance exercise and changes in maternal health outcomes.

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presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine. E. B., and A. A. conceived and designed research; E. B., A. A., and L. T. J. performed experiments; C. J. H., C. S., and F. D. S. analyzed data; C. J. H., C. S., and F. D. S. interpreted results of experiments; C. J. H., C. S., and F. D. S. drafted manuscript; C. J. H., E. B., A. A., and L. T. J. revised manuscript; all authors approved final version of manuscript. Supplementary data to this article includes the following: (i) Supplemental Table 1, Supplemental Digital Content, <https://links.lww.com/MSS/D320>. Weekly Aerobic Exercise Metrics, and (ii) Supplemental Figure 1, Supplemental Digital Content, <https://links.lww.com/MSS/D320>. Weekly average resistance exercise volume completed per exercise with associate average rating of perceived exertion.

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