Original research

Maternal physical activity prior to and during pregnancy does not moderate the relationship between maternal body mass index and infant macrosomia

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ABSTRACT

Objectives: Maternal body mass index (BMI) is a significant determinant of infant macrosomia. Given the strong metabolic effects of physical activity (PA), independent of body mass, it is unclear as to whether maternal PA may affect the risk of delivering a macrosomic infant. Thus, the purpose of this study was to determine if maternal PA moderates the relationship between maternal BMI and infant macrosomia.
Design: Cross-sectional study using data from the National Maternal and Infant Health Survey (1988).
Methods: Women with singleton pregnancies, delivering term (37–44 weeks), live-birth infants (n = 6390) were included in the analyses. Multiple logistic regression models were performed to determine the moderating effects of maternal self-reported PA in the preconception and prenatal periods on the risk of infant macrosomia after adjusting for maternal age, race/ethnicity, gestational age and weight gain, smoking and alcohol use, and infant sex.
Results: Mothers were on average 25 years of age and nearly 25% were overweight or obese. Prevalence of macrosomia was 9%. Overweight or obese women had increased odds of delivering a macrosomic infant (OR = 1.69, p < 0.0001; OR = 1.67, p = 0.0032, respectively). Nearly 50% and 42% of mothers reported participating in at least 30 min of moderate PA, three times per week in the preconception and prenatal periods, respectively. Neither maternal PA in the preconception (OR = 0.98, p = 0.34) nor prenatal (OR = 1.00, p = 0.13) periods moderated the association between maternal BMI and infant macrosomia.
Conclusions: Maternal BMI was a significant predictor of infant macrosomia. However, mothers participating in at least 90 min of PA per week in the preconception or prenatal periods did not moderate this association. More rigorous study designs and precise measurements of maternal PA and neonatal size are warranted.

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1. Introduction

The prevalence of infant macrosomia, defined as a birthweight greater than 4000 g, increased in the U.S. and other developed countries over the past 20 years.[1,2] Macrosomia predisposes newborns to altered growth trajectories and increases the risk of obesity and associated co-morbidities later in life.[3] Maternal body mass index (BMI) is a significant, positive predictor of macrosomia, where larger mothers tend to deliver larger infants.[4] This predisposition is a function of the mother's overall metabolic health, which influences the amount of nutrient-energy reaching the fetus.[5] Thus, because mothers with a greater BMI often have poorer metabolic health, their fetuses are often exposed to an excess of energy resulting in the development of a larger infant.[6,7]

Considerable scientific evidence demonstrates that participation in sufficient levels of physical activity (PA) exerts strong effects on metabolic health.[8] Given that maternal metabolic health underlies the relationship between maternal body mass and infant macrosomia, higher levels of maternal PA prior to and-or during pregnancy may help to prevent the development of overgrown infants, especially in large mothers. Rigorous evidence supports this hypothesis by demonstrating the effects of PA on several non-communicable diseases (NCDs), in non-pregnant populations.[9] Individuals participating in higher levels of PA exhibited reduced risk of several NCDs and specifically metabolic diseases such as type II diabetes mellitus, regardless of their weight status.[10] Thus, it is reasonable to suggest that the beneficial effects of PA on metabolic health found in non-pregnant populations may exist in the pre-

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conception and/or prenatal periods. If this is correct, then mothers engaging in higher levels of PA prior to and/or during pregnancy may have improved metabolic health, controlling energy supply to their fetuses, and subsequently less likely to deliver a macrosomic infant, regardless of their BMI.

Evidence regarding maternal PA as a potential moderator of the relationship between maternal BMI and infant macrosomia is limited.[11] To our knowledge, only one study evaluated this relationship and found that, for overweight or obese pregnant women, physical inactivity before pregnancy increased the risk of delivering a macrosomic infant compared to active women.[11] A limitation of that study was that the authors did not evaluate the impact of maternal PA in the *prenatal* period. It is possible that higher levels of maternal PA during the preconception and/or prenatal periods will affect infant macrosomia. As such, determining the influence of maternal PA prior to and during pregnancy on infant size is important, and these findings may better inform PA guidelines for pregnant and future pregnant women. No studies previously evaluated the potential moderating effects of maternal PA in the preconception and/or prenatal periods on neonatal size. Therefore, the purpose of this study was to determine if maternal physical activity moderates the relationship between maternal BMI and infant macrosomia.

2. Methods

Data for the present study were from The National Maternal Infant Health Survey (NMIHS). The NMIHS was conducted by the National Center for Health Statistics in 1988 in order to identify factors that may be related to poor pregnancy outcomes.[12] The NMIHS employed a follow-back survey design and sampled U.S. women who had a live birth, fetal death or infant death in 1988. To make inferences on a nationally representative sample, the NMIHS used a complex survey design that drew stratified samples of live births, fetal and infant deaths identified via registered birth and death certificates. Black, very low (<1500 g)- and moderately low-birthweight (2500–2499 g) infants were oversampled. For the purposes of this study, only singleton, live-birth infants and their mothers were included in the analyses.

A total of 13,417 live-birth infants were sampled. To identify factors related to poor pregnancy outcomes, mothers of these infants were mailed a 35-page questionnaire that inquired about several maternal, paternal and infant characteristics during the preconception, prenatal and postnatal periods. The average recall period, defined as the time between delivery of the infant and the receipt of the questionnaire, was 17 months. Of the 13,417 mothers, 74.2% (n = 9954) responded to the questionnaire. Some differences in the characteristics of mothers who responded and did not respond to the questionnaire were observed. Mothers between the ages of 20–39 years, White, married, had fewer than four children, received early prenatal care, achieved more education, and resided in the Midwest region of the U.S. were more likely to respond to the questionnaire. Mothers of low-birthweight (<2500 g) infants were less likely to respond to the questionnaire.

Infant macrosomia was the primary outcome variable in this study. Macrosomia was defined as a birthweight greater than 4000 g. Birthweight was defined as the weight of the infant, in grams, at the time of delivery. Birthweight and gestational age data were extracted from birth certificates. Birthweights less than 300 g or greater than 9000 g were considered implausible[13] and excluded from the analyses.

Maternal preconception body mass index (BMI) was calculated using the standard equation: $BMI = weight\,(\text{kg}) \div height\,(\text{m}^2)$. Mothers self-reported their preconception height and weight. In all the analyses, maternal preconception BMI was treated as a continuous variable.

Mothers self-reported their PA in the preconception and prenatal periods. Preconception PA was measured using the following question: *"Did you exercise or play sports at least three times a week before you got pregnant. . .include brisk walking for ½ hour or more, jogging, aerobic swimming etc.?"* The response was recorded as "yes" or "no." Prenatal PA was using the following question: *"How many months of this pregnancy did you engage in exercise or play sports for 30 minutes at least three times a week?"* Response values ranged from 0 to 10 months.

Several maternal and infant characteristics were considered potential covariates. Data were extracted from the mothers' questionnaire and infant birth certificate. Maternal demographic characteristics that were considered potential covariates were: age (in years) and race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Hispanic and Other). Maternal pregnancy-related factors included gestational weight gain (GWG) and parity. GWG was calculated as the difference in weight (in pounds) at the time of delivery and prior to pregnancy. Maternal behaviors included as covariates were smoking status and alcohol use. For these behaviors, the mothers self-reported the use of cigarettes or consumption of alcohol in the last 12 months prior to delivery (yes or no). Infant characteristics included sex (male or female) and gestational age (weeks). For live-birth infants, gestational ages less than 22 weeks or greater than 44 weeks were considered implausible and excluded from the analyses.

Of the 9953 mothers, 9146 women had singleton pregnancies. Of these women, 2052 women delivered pre-term infants (22–36 weeks), and 6390 women delivered a live-birth infant between 37 and 44 weeks gestation (i.e. full-term). In addition, of the women with singleton pregnancies (n = 9146), 264 women had implausible values for either gestational age (n = 248) or infant birthweight (n = 16), 455 women had missing data for either gestational age (n = 448) or birthweight (n = 7). The final sample size for this study was 6390 women.

To determine if maternal preconception PA and prenatal PA moderate the association between maternal BMI and infant macrosomia, we performed multiple logistic regression analyses. First, we examined the unadjusted main effects of maternal BMI on infant macrosomia. Second, we separately assessed the unadjusted main effects of preconception PA and prenatal PA in conjunction with maternal BMI on infant macrosomia. Third, to determine the unadjusted moderating effects of preconception PA and prenatal PA, we entered an interaction term between preconception PA and maternal BMI and an interaction between prenatal PA and maternal BMI, in separate models. Lastly, we entered the maternal and infant covariates sequentially.

Because the NMIHS employed a complex survey design to make inferences on a nationally representative sample, weights were generated to account for non-response and survey design and were included in all statistical analyses. All statistical analyses were performed in SAS statistical software version 9.4 (Cary, North Carolina). For the multiple logistic regression, with infant macrosomia as the outcome variable, odds ratios were estimated. An alpha level of 0.05 was used to denote statistical significance for all analyses.

3. Results

For the analytic sample, mothers were on average 25 years of age, and nearly 25% were overweight or obese. In the prenatal period, these women gained approximately 14 kg (30 lbs) and delivered full-term (39.6 ± 1.6 weeks), live-birth infants weighing nearly 3300 g (3.3 kg; 7 lbs 4 oz.). The prevalence of infant macrosomia (9.3%) was slightly above the current U.S. prevalence

Table 1
Maternal and infant sample characteristics.

Sample characteristics	Analytic sample		
	N	Mean	SD
Maternal			
Age (y)	6393	25.77	5.66
Race/ethnicity (%)	6393		
NH White	2745	42.94	–
NH Black	2868	44.86	–
Hispanic	566	8.85	–
Other	214	3.35	–
Body mass index (kg/m^2)	6393	23.05	4.63
Underweight (%)	623	9.75	–
Normal weight (%)	4181	65.40	–
Overweight (%)	489	17.21	–
Obese (%)	1100	7.65	–
Prenatal behaviors			
Smoking (% yes)	6393	28.44	–
Drinking (% yes)	6393	38.65	–
Preconception PA (% yes)	6393	48.47	–
Prenatal PA (% yes)	6393	42.37	–
Prenatal PA (no. of months)	6393	2.77	3.58
Infant			
Gestational age (weeks)	6393	39.63	1.60
Gestational weight gain (lbs)*	6393	13.94	8.05
Birthweight (g)	6390	3293.5	595.6
Macrosomia (%)	6393	9.31	–
Sex (%)			
Male	6393	50.99	–

Note: Between-group comparisons were performed using Student's t-test and Pearson's Chi-Square for continuous and categorical characteristics, respectively. The analytic sample was defined as women delivering full-term (37–44 weeks), live-birth infants in 1988. The excluded sample was defined as women delivering non-full-term infants (<37 weeks), or those with implausible gestational ages for live-births (<22 or >44 weeks). NH = Non-Hispanic. These values correspond to the raw data from the women sampled in the NMIHS survey, sample weights were not applied to account for the complex survey design.

* GWG represents the difference in weight (in lbs) at delivery and pre-pregnancy.

Table 2
Adjusted multiple logistic regression coefficients[a] for the moderating effect of maternal physical activity in the preconception period on the relationship between maternal body mass index and the odds of delivering a macrosomic infant (>4000 g).

Predictors	Parameter estimates			
	β	SE	OR	p-value
Primary exposures				
BMI (kg/m^2)[b]	0.09	0.01	1.09	<0.0001
Preconception PA[c]	0.39	0.50	1.48	0.44
BMI[d] preconception PA[c]	−0.02	0.02	0.98	0.34
Covariates				
Prenatal PA (no. of months)	−0.001	0.02	0.98	0.95
Gestational age (weeks)	0.21	0.03	1.24	<0.0001
Gestational weight gain	0.05	0.01	1.06	<0.0001
Smoking[d]	−0.76	0.13	0.47	<0.0001
Drinking[d]	0.07	0.11	1.08	0.5101
Infant sex[e]	0.58	0.11	1.78	<0.0001
Maternal age	0.03	0.01	1.03	0.0013
Maternal race/ethnicity[f]				
NH Black	−0.88	0.11	0.41	<0.0001
Other	−1.30	0.39	0.27	0.0009
Hispanic	−0.27	0.18	0.77	0.13

[a] Referent group for the outcome variable = average-for-gestational age (AGA). Only regression coefficients for large-for-gestational age are displayed. OR = odds ratio.
[b] BMI (body mass index) is calculated from preconception weight and height self-reported by the mother.
[c] 'No' is the referent group.
[d] 'No' is the referent group.
[e] 'Female' is the referent group.
[f] NH = Non-Hispanic, NH White is the referent group. Sample weights were applied to account for non-response and complex survey study design.

Table 3
Adjusted multiple logistic regression coefficients[a] for the moderating effect of maternal physical activity in the prenatal period (no. of months) on the relationship between maternal body mass index and the odds of delivering a macrosomic infant (>4000 g).

Predictors	Parameter estimates			
	β	SE	OR	p-value
Primary exposures				
BMI (kg/m^2)[b]	0.09	0.01	1.10	<0.0001
Prenatal PA	0.10	0.07	1.11	0.13
BMI[d] prenatal PA	−0.004	0.003	1.00	0.13
Covariates				
Preconception PA[c]	−0.08	0.13	0.93	0.55
Gestational age (weeks)	0.21	0.03	1.24	<0.0001
Gestational weight gain	0.05	0.01	1.06	<0.0001
Smoking[d]	−0.76	0.13	0.47	<0.0001
Drinking[d]	0.07	0.11	1.07	0.52
Infant sex[e]	0.58	0.11	1.78	<0.0001
Maternal age	0.03	0.01	1.03	0.0010
Maternal race/ethnicity[f]				
NH Black	−0.89	0.11	0.41	<0.0001
Other	−1.30	0.39	0.27	0.0010
Hispanic	−0.27	0.18	0.77	0.13

[a] Referent group for the outcome variable = average-for-gestational age (AGA). Only regression coefficients for large-for-gestational age are displayed. OR = odds ratio.
[b] BMI (body mass index) is calculated from preconception weight and height self-reported by the mother.
[c] 'No' is the referent group.
[d] 'No' is the referent group.
[e] 'Female' is the referent group.
[f] NH = Non-Hispanic, NH White is the referent group. Sample weights were applied to account for non-response and study design.

estimate (8%). Roughly 30% and 40% of mothers reported smoking and/or drinking in the 12 months prior to the birth of their child, respectively. In the *preconception* period, nearly 50% of mothers reported being active at least three times per week for at least 30 min. Forty-two percent of mothers reported being active at least three times per week for at least 30 min in the *prenatal* period. These mothers maintained this dose of PA for nearly three months (2.8 ± 3.8 months) of their pregnancy [see Table 1].

Preliminary analyses showed that maternal BMI was a significant, positive predictor of infant macrosomia. Specifically, overweight or obese mothers had increased odds of delivering a macrosomic infant compared to normal weight mothers (OR = 1.69, p < 0.0001; OR = 1.670, p = 0.0032, respectively). For the unadjusted *moderating effect* of maternal PA in the *preconception* period, our analyses revealed that participation in PA prior to pregnancy did not exhibit a moderating effect on the association between maternal BMI and the odds of delivering a macrosomic neonate (OR = 0.97, p = 0.16). Similarly, after adjusting for prenatal PA, gestational age and weight gain, maternal age and race/ethnicity, smoking and alcohol use, and infant sex, the *moderating effect* of maternal PA in the *preconception* period remained non-significant (OR = 0.98, p = 0.34) [see Table 2].

The unadjusted analysis for the *moderating effect* of maternal PA in the *prenatal* period showed that participation in PA during pregnancy significantly modified the association between maternal BMI and the odds of delivering a macrosomic infant (OR = 0.995, p = 0.04). However, after controlling for preconception PA, gestational age and weight gain, maternal age and race/ethnicity, smoking and alcohol use, and infant sex, the *moderating effect* of

PA in the *prenatal* period was no longer statistically significant (OR = 1.00, p = 0.13) [see Table 3].

4. Discussion

The purpose of this study was to evaluate the moderating effect of maternal physical activity in both the preconception and prenatal periods on the relationship between maternal BMI and infant macrosomia. Consistent with previous literature, our study found that maternal body mass was positively associated with the delivery of a macrosomic infant. However, there was no modifying effect of maternal PA in the preconception period on the association between maternal body mass and infant macrosomia. Similarly, in the prenatal period, maternal PA did not exert a modifying effect on this relationship. The present study was unique in that it was the first to determine the potential modifying effects of maternal PA both prior to and during pregnancy. Only one other study, to our knowledge, previously evaluated the modifying effect of maternal PA; however, that examination restricted their analysis to the preconception period.[11] Thus, the present study provides important information about the relationships between maternal PA and BMI and infant size.

Our observation that maternal PA in the *preconception* period does not modify the association between maternal BMI and infant macrosomia conflicts with the current literature. Only one other study previously evaluated this relationship and these authors found that in overweight or obese women, low levels of maternal PA prior to pregnancy increased the risk of delivering a macrosomic infant.[11] The inconsistent findings between these studies may be consequent to non-differential misclassification as result of the measurement tool used to assess maternal PA.[14] Both studies used a self-reported method to evaluate maternal PA, however, the questions used varied greatly. In the Krogsgaard et al.[11] study, women were asked to report the frequency, intensity and duration of the physical activities in which they participated in the preconception period. In the present study, women were asked about their participation in a specific dose of PA (i.e. three times/week for 30 min). The specificity of the PA dose potentially led to a misclassification of women as 'inactive' or 'active.' For example, if a woman participated in PA twice per week for 45 min, an equivalent dose of PA, might result in the incorrect classification as 'inactive' given she did not meet the three-day per week requirement. In addition, the PA question used in this study did not explicitly state any level of PA intensity (i.e. light, moderate or vigorous), although a moderate level of intensity was implied in the example activities (e.g. brisk walking, aerobics). Nonetheless, women achieving the adequate dose of PA at a lower intensity may have been misclassified as 'active.' Consequently, the possibility of non-differential misclassification may have diluted the potential modifying effect of maternal PA, explaining our null observation. Thus, more open-ended questions or objective assessments could provide information that more accurately reflects maternal PA behavior prior to pregnancy.

In the present study, maternal PA in the *prenatal* period exhibited no moderating effect on the relationship between maternal BMI and neonatal size. A possible explanation for this null observation is that the dose of PA in which these women engaged was insufficient to affect maternal metabolic health and subsequently infant macrosomia. Importantly, population-level declines in maternal PA have been observed since 1965.[15] In this study, women were considered 'active' if they participated in PA three times per week for at least 30 min. This amount of PA is less than the dose recommended by the United States Department of Health and Human Services and endorsed by the American College of Obstetricians and Gynecologists.[16,17] These entities encourage pregnant women to engage in at least 150 min of activity per week. Currently, no scientific evidence identifies a specific dose of PA known to reduce the risk of infant macrosomia, however, women with gestational diabetes (i.e. enhanced fetal energy supply) are encouraged to participate in 30–60 min of moderate PA at least three times per week. Studies examining the effects of this dose of PA among type II diabetic or gestationally-diabetic women reported a reduced risk of mothers delivering macrosomic infants.[18,19]

In addition to low levels of maternal PA, it is likely that these women participated in less PA throughout the prenatal period as it is well-documented that maternal PA declines in pregnancy.[20,21] In support of this, the women in this study reported participating in at least 90 min of PA per week for only three months of their pregnancy. This suggests that their PA declined, mostly likely in the final two trimesters, however we are unable to quantify the extent to which it decreased. Scientific evidence demonstrates that mothers decreasing their PA in mid- to late-pregnancy can lead to the birth of larger infants, but this effect is likely dependent on the magnitude of the decline in PA.[22] In the current study, due to the likely low levels of maternal PA in the first three months of pregnancy, the decline in PA would be minimal thus, unlikely to influence infant size.

Another potential explanation for the null observation of maternal PA in the *prenatal* period as a modifier is non-differential misclassification of maternal PA behavior. The question evaluating maternal PA in the *prenatal* period was similar to the question assessing PA in the *preconception* period, as such, suffers from the same limitations. However, a unique self-reporting bias may be present due to the PA guidelines endorsed at the time of this study (1988). In 1985, ACOG developed the inaugural PA guidelines for pregnant women which recommended, with strict limitations, that women can engage in most aerobic PA but not reach a heart rate higher than 140 bpm and/or surpass 15 min of strenuous physical activity.[23] Consequently, the specified dose of PA mentioned in the PA survey question may have led women to misclassify themselves as "inactive" given the restrictions of the 1985 PA guidelines. Engaging in amounts of PA greater than the most current guidelines may have been perceived as "unhealthy," posing an increased risk of harm to the fetus, despite no scientific evidence confirming that perception. In addition to this limitation, the extensive recall period possibly contributed to the misclassification. The average recall period, defined as the time that lapsed between the delivery of the infant and the receipt of the maternal questionnaire, was 17 months.[12] Thus, the ability of the mother to provide an accurate recall of her PA behavior during her pregnancy (or before pregnancy) was significantly diminished. Evidence demonstrates that there is an inverse relationship between length of the recall period and the ability of an individual to accurately recall their behavior.[24] Due to these considerable limitations of the measurement tool used to assess maternal PA, it is possible that our null observation is attributed to non-differential misclassification. As a result, the potential modifying effect of maternal PA in the prenatal period on the relationship between maternal BMI and infant macrosomia was diluted.[14]

This study has strengths and limitations. Foremost, this was the first study to evaluate maternal PA in the preconception and prenatal periods as a modifier of the relationship between maternal body mass and infant macrosomia. Second, the study was conducted using a large, diverse, nationally representative sample of women delivering singleton, full-term, live-birth infants in the United States.[12] As such, our findings are generalizable to a large sample of women. However, the present study also has limitations. First, maternal PA and BMI were measured via self-reporting methods. This type of assessment is notorious for producing less accurate estimates of behavior compared to objective assessments.[25] Consequently, the use of these imprecise and error-prone tools likely led to biased, misestimated associations.[26] Second, we did not consider other documented health behaviors known to influence infant size, including maternal diet.[27] Third, although infant birthweight is the most widely used metric for infant size, it has limitations. This metric is unable to capture vital details about infant size includ-

ing tissue composition (i.e. fat and fat-free mass) that are key to future health risks of these neonates. Lastly, macrosomia is poorly defined in the current literature. The birthweight thresholds that define macrosomia vary greatly in the literature (i.e. >4000, >4500, >5000 g).[28,29] As such, it is possible that we inappropriately classified infants.

In the present study it was observed that higher levels of maternal PA, at least 90 min per week, in the preconception and/or prenatal periods did not exhibit a modifying effect on the relationship between maternal BMI and infant size. This was the first study to evaluate this relationship and thus it provides important information about these relationships and contributes to the rapidly growing field of maternal-child health. Future studies should address the limitations of the present study. First, more precise assessments of maternal PA behavior and maternal and infant anthropometrics are necessary. Second, future researchers should include the assessment of metabolic biomarkers, such as serum glucose and lipids. Evidence identifies these factors as the mechanisms that underlie these relationships; however, studies tend to exclude these parameters. In conclusion, the findings of this study provide no evidence that mothers accumulating at least 90 min of PA per week in the preconception or prenatal periods modified the association between maternal BMI and infant macrosomia. Despite these findings, scientific evidence shows that maternal participation in PA during pregnancy provides numerous maternal-infant health benefits in the prenatal and postnatal periods.[30]

Practical implications

- Maternal body mass strongly determines the size of an infant, suggesting an increased risk of infant macrosomia among overweight and obese mothers.
- Maternal physical activity prior to during pregnancy did not attenuate this relationship.
- The use of imprecise measurements for both maternal body mass and behaviors and infant size, may have resulted in the null findings reported in this study.

References

1. Bell R. Trends in birthweight in the north of England. *Hum Fertil* 2008; 11(1):1–8. http://dx.doi.org/10.1080/14647270701654369.
2. Martin JA, Hamilton BE, Osterman MJ et al. Births: final data for 2013. *Natl Vital Stat Rep* 2015; 64(1):1–65.
3. Giles LC, Whitrow MJ, Davies MJ et al. Growth trajectories in early childhood, their relationship with antenatal and postnatal factors, and development of obesity by age 9 years: results from an Australian birth cohort study. *Int J Obes* 2015; 39(7):1049–1056. http://dx.doi.org/10.1038/ijo.2015.42.
4. Liu P, Xu L, Wang Y et al. Association between perinatal outcomes and maternal pre-pregnancy body mass index. *Obes Rev* 2016; 17(11):1091–1102. http://dx.doi.org/10.1111/obr.12455.
5. Walton A, Hammond J. The maternal effects on growth and conformation in shire horse–shetland pony crosses. *Proc R Soc Lond Ser B Biol Sci* 1938; 125(840):311. http://dx.doi.org/10.1098/rspb.1938.0029.
6. Herrera E. Lipid metabolism in pregnancy and its consequences in the fetus and newborn. *Endocrine* 2002; 19(1):43–55. http://dx.doi.org/10.1385/ENDO:19:1:43.
7. Pedersen J. Diabetes mellitus and pregnancy: present status of the hyperglycaemia–hyperinsulinism theory and the weight of the newborn baby. *Postgrad Med J* 1971;(Suppl):66–67.
8. Shojaee-Moradie F, Baynes KC, Pentecost C et al. Exercise training reduces fatty acid availability and improves the insulin sensitivity of glucose metabolism. *Diabetologia* 2007; 50(2):404–413. http://dx.doi.org/10.1007/s00125-006-0498-7.
9. Blair SN, Kohl 3rd HW, Barlow CE et al. Influences of cardiorespiratory fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. *JAMA* 1996; 276(3):205–210.
10. Gaesser GA, Angadi SS, Sawyer BJ. Exercise and diet, independent of weight loss, improve cardiometabolic risk profile in overweight and obese individuals. *Phys Sportsmed* 2011; 39(2):87–97.
11. Krogsgaard S, Gudmundsdottir SL, Nilsen TIL. Prepregnancy physical activity in relation to offspring birth weight: a prospective population-based study in Norway: the HUNT study. *J Pregnancy* 2013. http://dx.doi.org/10.1155/2013/780180. Article ID 780180, 6 pages.
12. Sanderson M, Gonzalez JF. 1988 National Maternal and Infant Health Survey: methods and response characteristics. *Vital Health Stat 2* 1998;(125):1–39.
13. Talge NM, Mudd LM, Sikorskii A et al. United States birth weight reference corrected for implausible gestational age estimates. *Pediatrics* 2014; 133(5):844–853.
14. Wacholder S, Hartge P, Lubin JH et al. Non-differential misclassification and bias towards the null: a clarification. *Occup Environ Med* 1995; 52(8):557–558.
15. Archer E, Lavie CJ, McDonald SM et al. Maternal inactivity: 45-year trends in mothers' use of time. *Mayo Clin Proc* 2013; 88(12):1368–1377.
16. Artal R, O'Toole M. Guidelines of the American College of Obstetricians and Gynecologists for exercise during pregnancy and the postpartum period. *Br J Sports Med* 2003; 37(1):6–12. http://dx.doi.org/10.1136/bjsm.37.1.6.
17. United States Department of Health and Human Services. 2008 Physical Activity Guidelines for Americans. Office of Disease Prevention and Health Promotion. Retrieved from: http://health.gov/paguidelines/pdf/paguide.pdf.
18. Brown J, Alwan NA, West J et al. Lifestyle interventions for the treatment of women with gestational diabetes. *Cochrane Database Syst Rev* 2017;(5). http://dx.doi.org/10.1002/14651858.CD011970.pub2.
19. Wang C, Guelfi KJ, Yang H-X. Exercise and its role in gestational diabetes mellitus. *Chronic Dis Transl Med* 2016; 2(4):208–214. http://dx.doi.org/10.1016/j.cdtm.2016.11.006.
20. Huberty JL, Buman MP, Leiferman JA et al. Trajectories of objectively-measured physical activity and sedentary time over the course of pregnancy in women self-identified as inactive. *Prev Med Rep* 2016; 3:353–360. http://dx.doi.org/10.1016/j.pmedr.2016.04.004.
21. Renault K, Norgaard K, Secher NJ et al. Physical activity during pregnancy in normal-weight and obese women: compliance using pedometer assessment. *J Obstet Gynaecol* 2012; 32(5):430–433. http://dx.doi.org/10.3109/01443615.2012.668580.
22. Clapp III JF, Kim H, Burciu B et al. Continuing regular exercise during pregnancy: effect of exercise volume on fetoplacental growth. *Am J Obstet Gynecol* 2002; 186(1):142–147.
23. Downs DS, Chasan-Taber L, Evenson KR et al. Physical activity and pregnancy: past and present evidence and future recommendations. *Res Q Exerc Sport* 2012; 83(4):485–502.
24. Ainsworth BE, Caspersen CJ, Matthews CE et al. Recommendations to improve the accuracy of estimates of physical activity derived from self report. *J Phys Act Health* 2012; 9(01):S76–S84.
25. Bell R, Tennant PW, McParlin C et al. Measuring physical activity in pregnancy: a comparison of accelerometry and self-completion questionnaires in overweight and obese women. *Eur J Obstet Gynecol Reprod Biol* 2013; 170(1):90–95. http://dx.doi.org/10.1016/j.ejogrb.2013.05.018.
26. Archer E, Hand GA, Blair SN. Validity of US nutritional surveillance: National Health and Nutrition Examination Survey caloric energy intake data, 1971–2010. *PLoS One* 2013; 8(10):e76632.
27. Grieger JA, Clifton VL. A review of the impact of dietary intakes in human pregnancy on infant birthweight. *Nutrients* 2014; 7(1):153–178. http://dx.doi.org/10.3390/nu7010153.
28. Koyanagi A, Zhang J, Dagvadorj A et al. Macrosomia in 23 developing countries: an analysis of a multicountry, facility-based, cross-sectional survey. *Lancet* 2016; 381(9865):476–483. http://dx.doi.org/10.1016/S0140-6736(12)61605-5.
29. Ye J, Torloni MR, Ota E et al. Searching for the definition of macrosomia through an outcome-based approach in low- and middle-income countries: a secondary analysis of the WHO Global Survey in Africa, Asia and Latin America. *BMC Pregnancy Childbirth* 2015; 15:324. http://dx.doi.org/10.1186/s12884-015-0765-z.
30. Melzer K, Schutz Y, Soehnchen N et al. Effects of recommended levels of physical activity on pregnancy outcomes. *Am J Obstet Gynecol* 2010; 202(3). http://dx.doi.org/10.1016/j.ajog.2009.10.876, 266.e1–6.