Variation in newborn size according to pregnancy weight change by trimester[1–3]

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ABSTRACT

Background: The timing of maternal weight change in pregnancy may be an important determinant of the newborn's size.

Objective: The purpose was to identify effects of maternal weight change by trimester on newborn size, under the hypothesis that low weight gain early in pregnancy predicts proportionately smaller newborns.

Design: Women planning to become pregnant were followed by clinic visits and questionnaires through delivery. This study includes 389 women and their singleton infants born at a gestational age of ≥241 d.

Results: In multiple regression analyses including a variety of potential confounders, maternal weight gain in the first and second trimesters predicted newborn weight (1-kg weight gain in the first trimester predicted a 31-g increase in newborn weight, $P < 0.0007$, and 1-kg weight gain in the second trimester predicted a 26-g increase in newborn weight, $P < 0.007$), but weight gain in the third trimester did not. Newborn ponderal index (in kg/m^3) was predicted by weight gain in the first (1-kg weight gain predicted an added 0.21 units, $P < 0.0003$) and third (1-kg weight gain predicted an added 0.12 units, $P < 0.03$) trimesters but not in the second trimester. Newborn weight was 211 g lower ($P < 0.006$) and ponderal index 1.2 units lower ($P < 0.02$) in infants born to women who lost weight in the first trimester.

Conclusions: The use of measured prepregnancy weight in tests of the effect on newborn size of weight gain by time in pregnancy produces different results than does the use of recalled prepregnancy weight. Maternal weight change in the first trimester of pregnancy more strongly influences newborn size than does weight change in the second or third trimester. *Am J Clin Nutr* 2002;76:205–9.

KEY WORDS Pregnancy, maternal weight gain, fetal growth, birth weight, ponderal index

INTRODUCTION

Newborn size is an important indicator of infant survival and childhood morbidity (1) and appears to be related to subsequent risk of type 2 diabetes, hypertension, cardiovascular disease, and other disorders (2, 3). Therefore, many studies have attempted to identify sources of variation in newborn size. Total maternal weight gain in pregnancy is a well-established, modifiable influence on newborn size (4), but less is known about the effects of weight change by time in pregnancy. Studies have generally found maternal weight gain in the first trimester of pregnancy to be unrelated to birth weight (5–7) and weight gain in the second trimester (5, 8) or the second and third trimesters (6, 7, 9, 10) to be related. Previous studies were based on recalled prepregnancy weight rather than on measured weight. It is possible that the use of recalled prepregnancy weight introduces sufficient error to make it difficult to detect the effects of first-trimester maternal weight change on newborn size.

The purpose of the current study was to identify effects of maternal weight change by trimester of pregnancy on weight, length, head circumference, and ponderal index (PI; in kg/m^3) of newborns. It was hypothesized that smaller weight gains in early pregnancy would predict proportionately smaller newborns.

SUBJECTS AND METHODS

The study was conducted among women enrolled in the Diana Project, a population-based, prospective study of effects of preconceptional and pregnancy nutritional exposures on reproductive outcomes. Information on eligibility criteria, recruitment methods, sample retention, characteristics of the subjects, and reproductive outcomes is available in a separate publication (11). Volunteers for the Diana Project were recruited primarily by mail from 1989 to 1992 from the population of women aged 22–35 y enrolled in Group Health, Inc, a managed-care organization serving the Greater Minneapolis–St Paul area of Minnesota. Births occurred to participants through 1993. Women were eligible for the study if they intended to become pregnant within the enrollment period; had not been attempting pregnancy for ≥3 mo; had

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delivered their last infant ≥12 mo before enrollment; did not intend to use contraceptive methods during the study; had no history of hypertension, renal disease, diabetes mellitus, heart disease, or infertility; and submitted a signed consent form. Recruitment efforts resulted in 2840 contacts from potential participants; 1152 were eligible and were enrolled. Of these 1152 women, 84% (n = 968) completed the study to an endpoint and 706 delivered liveborn singleton infants. This study includes 389 of these women whose pregnancies lasted ≥241 d from conception and for whom data on preconceptional weight and height within 6 mo of conception or 2 wk after conception and on weight within 25 d of the end of each trimester are available. Weeks included in each trimester consist of 0 to <12.7 wk for the first trimester, 12.7 to <25.4 wk for the second, and ≥25.4 wk for the third trimester. The research was approved by the institutional review board, and women were paid $100 for full participation in the study.

Study protocol

Independent effects of maternal weight gain in each trimester of pregnancy, total pregnancy weight gain, and weight loss in the first trimester on newborn weight, length, head circumference, and weight-for-length (PI) of newborns were tested in multiple regression analyses. Potential confounders to these relations consisted of the mother's birth weight, parity, and age at conception; preconception body mass index (BMI; in kg/m^2), height, and weight; diagnoses of gestational diabetes, chronic and gestational hypertension, and infection (yes or no); nausea and vomiting in the first trimester (yes or no); smoking during pregnancy (yes or no); and the sex and gestational age of the newborn. The sample was restricted to singletons with gestation ≥241 d to limit the effects of early delivery on the relation of pregnancy weight gain and newborn size.

Data for the Diana Project were collected by interviews and from measurements obtained during clinic visits, from mailed questionnaires, and from medical records by trained abstractors. Each mother's birth weight, parity (number of previous live births), and age at conception and the occurrence and frequency of nausea and vomiting in the first trimester were identified by self-administered questionnaires. Weight without clothing, measured on home scales, was reported weekly by women and was measured on calibrated beam-balance scales during periodic study visits. A home scale was provided for each woman who needed it. Study visits were scheduled once before pregnancy, every 3 mo during pregnancy, and once within 6 and 8 wk postpartum. Home weights correlated highly with weights measured in the clinic (r = 0.98) and are used here. Weight was measured <6 mo before conception in 364 women and within 2 wk after conception in the remaining 25. The last first-trimester weights used in analyses were from 70 to 98 d of gestation, and the last second-trimester weights were those from 160 to 183 d. The last measure of pregnancy weight gain was within 1 wk of delivery in 354 women, within 2 wk of delivery in 22, and within 22 d of delivery in 13. The height of subjects, not wearing shoes, was measured during the first preconception clinic visit by trained, periodically monitored, certified nurse midwives, nurse practitioners, or other health professionals who used a stationary stadiometer. Diagnoses of gestational diabetes and gestational and chronic hypertension were taken from medical records. Documentation in the medical record of at least one diagnosed infection, such as chlamydia, viral syndrome, herpes, or urinary tract infection, during pregnancy qualified women for a "yes" response to prenatal infection.

Gestational age of newborns was estimated as the number of days from conception to delivery. In most cases, the day of conception was calculated from monthly menstrual records (date of the first day of the next expected menstrual cycle minus 14 d). It was obtained from newborn records when menstrual cycle data were incomplete. Newborn size outcomes of weight, length, and head circumference were gathered from medical records. Birth weight was assessed on a digital scale shortly after birth and while the newborn was naked. Placenta weights were not available in the medical record. Preferred values for length and head circumference were those measured at the routinely scheduled, 2-wk postpartum visit when the legs were more flexible and head circumference was less affected by delivery. Length was generally measured while the infant lay on a sheet of paper with the knees being slightly bent by the clinician. The paper was marked at the bottom of the infant's heels and then at the top of the head, and the interval measured with a tape and recorded. For a few infants, measures of length at birth were used after adjustment for time trend.

Characteristics of the women included in the analyses (n = 389) were compared with those of women in the Diana Project for whom data were incomplete and who were excluded (n = 292). Women providing complete data differed from women with incomplete data in that parity was higher among women with complete data (0.47 ± 0.69 and 0.29 ± 0.64 live births, respectively; P < 0.001). No significant difference was found between participants included and those not included with regard to mean maternal age, preconception weight, or height or newborn gestational age, birth weight, or length (54.0 ± 7.0 and 53.3 ± 2.3 cm, respectively). No significant differences in categories of diagnosed infection, smoking, household income, or race were apparent between the 2 groups.

Statistical analyses

Covariance between independent variables was assessed by correlations. Multiple regression models (PROC GLM, SAS, version 6.12; SAS Institute Inc, Cary, NC) were used to assess independent effects of the weight change during a trimester on newborn size outcomes while controlling for potential confounding. Total weight gain was entered into final models in place of trimester weight gain to test consistency of the results. Interaction terms testing the effects of preconception BMI and trimester weight gain on newborn size outcomes were entered into final regression models. Predicted and mean newborn weight and PI by trimester weight gain were calculated. Slopes of weight gain and birth weight or PI by trimester were compared by putting the 3 trimester slopes into a single linear model as explanatory variables.

To specifically identify whether low maternal weight change in the first trimester affects newborn size, we divided women into 3 groups: those losing weight (n = 41) and those gaining less (n = 174) or more (n = 174) weight than the median (2.7 kg). These groups were entered into regression models along with weight gain in the second and third trimesters and the other independent variables in the final regression models.

RESULTS

Sample characteristics are shown in **Table 1**. Women gained an average of 15.6 kg during pregnancy. Weight gain by trimester

TABLE 1
Sample characteristics of pregnant women (n = 389) and their singleton newborns of ≥241 d gestation

Characteristic	Value
Maternal	
White (%)	97
Preconception BMI (kg/m^2)	22.5 ± 3.2 (19.2, 26.9)[1]
Preconception weight (kg)	61.2 ± 9.4 (50.7, 73.2)
Preconception height (m)	1.6 ± 0.1 (1.57, 1.73)
Age at conception (y)	29.4 ± 3.1 (25.3, 33.7)
Parity (no. of live births)	0.5 ± 0.7 (0, 1)
Gravida (%)	
1	56
2	29
3	12
4	3
Total pregnancy weight gain (kg)	15.6 ± 4.1 (10.5–21.4)[2]
First trimester	2.3 ± 2.1[3]
Second trimester	7.0 ± 2.0
Third trimester	6.3 ± 2.4
Newborn	
Birth weight (g)	3575 ± 448 (3033–4167)
<2500 (%)	1.0
>4500 (%)	3.1
Ponderal index (kg/m^3)	23.5 ± 2.4 (20.7–26.7)
Gestational age (d)	266 ± 9.9 (253–278)
Female (%)	47
Household income (%)	
<$30 000/y	15
>$50 000/y	44
Employed for pay (%)	90

[1] $\bar{x}$ ± SD; 10th, 90th percentiles in parentheses.
[2] $\bar{x}$ ± SD; range in parentheses.
[3] $\bar{x}$ ± SD.

of pregnancy was independently related to newborn weight and PI (**Table 2**), but not to length or head circumference. Variables not retained in newborn weight and PI models at $P < 0.05$ consisted of the mother's birth weight, preconception weight, diagnosed gestational diabetes, gestational and chronic hypertension, infection, nausea and vomiting, and smoking during pregnancy. Specifically, each kilogram of weight gained by the mother in the first and second trimester predicted a 31-g and 26-g increase in newborn weight, respectively, when the effects of other covariates were controlled for. Weight gain in the third trimester was not predictive of newborn weight. Newborn PI was predicted by maternal weight gain in the first and third trimesters of pregnancy. Each kilogram of weight gained in the first trimester added an estimated 0.21 units to newborn PI in the first trimester and 0.12 units in the third trimester. Weight gain in the second trimester was not related to newborn PI.

Comparisons of the slopes of the relation of trimester maternal weight gain to birth weight showed that slopes in the first and second trimesters were similar (≈30 g/kg) and markedly greater than the slope in the third trimester (≈7 g/kg). The magnitude of the difference in slopes was not significant (P = 0.14), but it is likely of clinical importance. Pairwise comparisons detected no significant difference between the first- and second-trimester slopes (P = 0.74) or between the second- and third-trimester slopes (P = 0.16). Differences between the slopes of the first and third trimesters and in the sum of the first and second trimesters bordered on significance (P = 0.059 and 0.052, respectively). Slopes of trimester weight gain and PI showed a nonsignificant trend toward being different (P = 0.19), and the evidence for such differences was somewhat stronger in pairwise comparisons.

The low numbers of overweight and obese women in this sample limited our ability to examine interactions of preconception BMI and weight gain on newborn size outcomes. Such interactions were not identified. Although nonsignificant, a trend was noted that suggested, among women with lower preconception weight, an increased effect of first-trimester weight gain on the weight of their newborns (51 kg preconception weight, 51 g/kg weight gain; 62 kg preconception weight, 41 g/kg weight gain; and 79 kg preconception weight, 17 g/kg weight gain.) A similar but somewhat weaker, nonsignificant trend was observed in the second trimester. The relation between newborn weight and the third-trimester weight gain among heavy women (79 kg) suggests that birth weight may decline slightly (−6 g/kg weight gain) with increasing maternal weight gain. Such trends were not observed for newborn PI.

Predicted and mean newborn weight and PI by trimester maternal weight gain are shown in **Figure 1**. Maternal weight gains of 0–4 kg in the first trimester and of 4–10 kg in the second trimester were strongly and positively related to newborn weight among the liveborn singleton infants included in the sample. The slope representing the relation of third-trimester maternal weight gain and newborn weight shows a limited effect. Slopes representing predicted relations between trimester maternal

TABLE 2
Final regression models of effects of trimester weight gain on newborn weight and ponderal index (n = 389)[1]

	Birth weight (g)			Ponderal index (kg/m^3)		
Variable	b	SE	P	b	SE	P
Weight gain (kg)						
First trimester	31	9	0.0007	0.21	0.06	0.0003
Second trimester	26	10	0.007	0.05	0.06	0.40
Third trimester	7	8	0.40	0.12	0.05	0.03
Gestational age (d)	15	2	0.0001	—	0.01	—
Sex (female)	−210	38	0.0001	—	0.24	—
Parity (no. of live births)	171	28	0.0001	0.52	0.18	0.004
Mother's height (m)	1.7	0.3	0.0005	—	2.0	—
Mother's age (y)	−21	6	0.001	—	0.04	—
Preconception BMI (kg/m^2)	21	6	0.0005	0.11	0.04	0.003
Intercept	−3045	777	0.0001	13.60	4.99	0.007

[1] Sample limited to liveborn singleton infants with gestational age ≥241 d at delivery. For birth weight, model F = 21.75, P = 0.0001, and R^2 = 0.34. For ponderal index, model F = 4.32, P = 0.0001, and R^2 = 0.10.

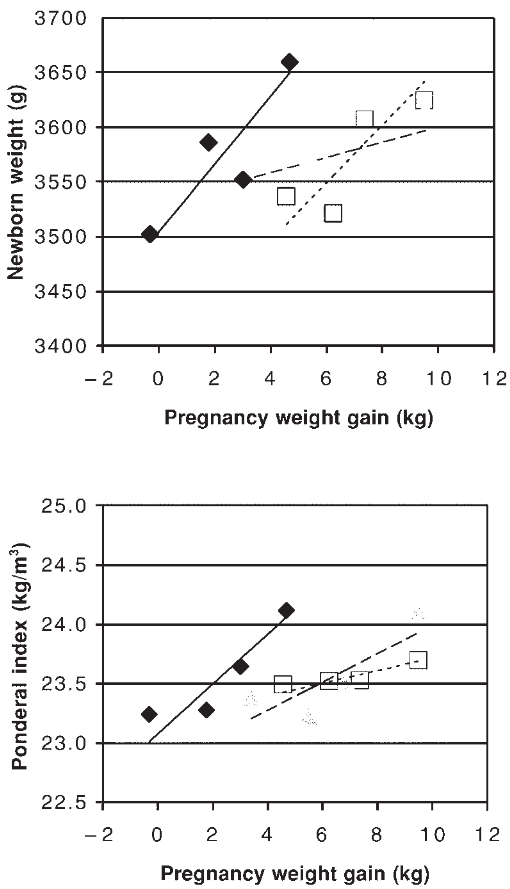

FIGURE 1. Predicted and mean newborn weight and ponderal index by trimester weight gain in 389 pregnant women and newborns with gestational age of ≥241 d. Means were calculated within quartiles of weight gain in each trimester and are adjusted for maternal age, height, BMI, and parity; infant sex and gestational age; and maternal weight gain in the other 2 trimesters. In modeling of predicted values, covariates were held constant at mean value for sample. ———: first-trimester gain, predicted; ◆: first-trimester gain, mean; - - - - -: second-trimester gain, predicted; □: second-trimester gain, mean; — — — —: third-trimester gain, predicted; ▲, third-trimester gain, mean.

weight gain and newborn PI show predominant effects of first-trimester gain on PI.

Models testing consistency of results with the use of total maternal pregnancy weight gain in place of trimester gains identified the same significant predictors as did the trimester weight-gain models (data not shown). Each kilogram of total pregnancy weight gain was related to a 20-g increase in birth weight ($P < 0.0001$) and a 0.13-unit increase in PI ($P < 0.0001$). The model for effects of total maternal weight gain on newborn weight was significant ($F = 27.27$, $P < 0.0001$, $R^2 = 0.33$), as was that for PI ($F = 5.07$, $P < 0.0001$, $R^2 = 0.09$).

Regression models including categorical variables for weight change during the first trimester and the other covariates identified an estimated 211-g lower newborn weight ($F = 8.51$, $P < 0.006$) and a 1.2-unit lower PI ($F = 4.20$, $P < 0.02$) among infants born to women who lost weight ($n = 41$) than among infants born to women whose weight gain was above the median ($n = 174$, first-trimester weight gain ≥2.7 kg). Few women lost weight in the second or third trimester.

DISCUSSION

The results of this study differ from those of previous reports in that maternal weight gain occurring primarily in the first and second trimesters of pregnancy predicted newborn weight. Maternal weight gain in the first trimester was found in the past to be unrelated to newborn weight (5, 6, 8), whereas gains in the second trimester or in both the second and third trimesters have been related to newborn weight (5–10). This appears to be the first report of associations between maternal weight gain by trimester and newborn weight-for-length. Assessed as PI, newborn weight-for-length was predicted by maternal weight gain in the first trimester and weakly predicted by that in the third trimester. Although it is speculative, the fetal weight trajectory may be influenced by early maternal weight gain in pregnancy and may be minimally modifiable by late pregnancy weight gain. Increases in PI in the third trimester without concomitant increases in length suggest that fetal body fat and lean tissue mass increased. Because the fetus does not accumulate fat or much lean tissue in the first trimester, early maternal weight gain may act to predispose the fetus to differing levels of fat and lean tissue gain later in gestation.

Differences in results between this and other studies may stem in part from our use of prospectively measured preconception weight rather than recalled prepregnancy weight. In a study by Yu and Nagey (12), women in the first trimester of pregnancy who were asked to recall their prepregnancy weight underestimated it by an average of 4.3 lb. Others have noted that the discrepancy between actual and recalled weight appears to increase as weight increases (13). In the current study, women gained an average of 4.9 lb during the first trimester, about the amount of the likely underestimation in studies using recalled weight. The effect of underestimation of preconception weight is an overestimation of subsequent pregnancy weight gain. For example, a woman who reports weighing 130 lb before pregnancy, but who actually weighed 134 lb, will be noted to have gained 4 lb more than she actually did when her weight is first measured during a prenatal visit. An actual weight loss of 2 lb, therefore, would be recorded as a 2-lb gain. Errors introduced by misestimation of prepregnancy weight would obscure effects of first-trimester weight change on newborn size.

It has often been assumed that pregnancy weight gain among women with high preconception weight should be postponed until late in pregnancy. The results of this study indicate, however, that maternal weight gain in the third trimester does not affect newborn weight, length, or head circumference, but rather affects PI. Consequently, postponing weight gain until late in pregnancy may be of limited benefit for fetal size, and it may promote postpartum weight retention for the mother. To and Cheung (14) noted that women who gain weight excessively after midpregnancy retained more weight, and their pregnancy weight gain had a more limited effect on birth weight than was the case in women who gained weight early but did not gain weight excessively in late pregnancy. In the current study, third-trimester maternal weight gain did not predict newborn weight, but it did predict newborn PI. Weight gain in the third trimester of pregnancy may play a role in preventing the birth of thin newborns and potentially decrease the risk later in life of certain chronic diseases that are associated with thinness at birth.

The lack of relation of trimester maternal weight gain to newborn length and head circumference seen here may have been due to the inclusion in this study of healthy, well-educated, and fairly health-conscious women. Nonetheless, newborn length and head circumference did appear to be more refractory to effects of weight change by time in pregnancy than was newborn weight in this sample.

The results reported here with regard to early weight change in pregnancy and newborn size outcomes have several important implications. They call into question the ability of food or nutrient supplementation trials beginning after the first trimester of pregnancy to fully test effects of those supplements on newborn size outcomes. In addition, the window of opportunity for enhancing fetal growth may be limited by a delay in prenatal care and the provision of nutrition programs, such as the Supplemental Food and Nutrition Program for Women, Infants, and Children, and other nutrition program benefits after the first trimester.

The results of this research should be interpreted in light of the study's limitations. The sample consisted largely of white, middle-income women with a reliable source of health care. It is not possible to conclude that the effects observed would be the same in other groups of women. However, results that represent biological relations are likely to apply to pregnant women from various ethnic groups and different socioeconomic strata. In addition, other potential reasons for reductions in newborn weight and weight-for-length, such as placental abnormalities and genetic predispositions toward reduced fetal growth, exist and are not explored here. Too few women in this study smoked or had a diagnosis of gestational diabetes or hypertension during pregnancy for a confident testing of the effects of those factors on newborn size outcomes or the relation to pregnancy weight gain.

Errors in newborn size measures likely resulted from the use of medical record data. It is unlikely that the measures were systematically biased, however. Of the 3 measures, birth weight was probably the most accurate. Errors in measures would likely attenuate the effects somewhat. Changes in women's weights between 6 mo before conception and conception may also have introduced error that would modify effects related to early weight change.

These results indicate that several assumptions about relations between early pregnancy weight change and newborn size outcomes may not hold up when tested under a prospective study design. If confirmed in future studies, these results may change views of the effects of timing of prenatal nutrition and other exposures on fetal growth and development and, possibly, later disease risk.

REFERENCES

1. McCormick MC. The contribution of low birth weight to infant mortality and childhood morbidity. N Engl J Med 1985;312:82–90.
2. Mi J, Law C, Zhang KL, Osmond C, Stein C, Barker D. Effects of infant birthweight and maternal body mass index in pregnancy on components of the insulin resistance syndrome in China. Ann Intern Med 2000;132:253–60.
3. Godfrey KM. Maternal regulation of fetal development and health in adult life. Eur J Obstet Gynecol Reprod Biol 1998;78:141–50.
4. National Academy of Sciences. Nutrition during pregnancy. I. Weight gain. II. Nutrient supplements. Washington, DC: National Academy Press, 1990:176–221.
5. Hickey CA, Cliver SP, McNeal SF, Hoffman HJ, Goldenberg RL. Prenatal weight gain patterns and birth weight among nonobese black and white women. Obstet Gynecol 1996;88:490–6.
6. Strauss RS, Dietz WH. Low maternal weight gain in the second or third trimester increases the risk for intrauterine growth retardation. J Nutr 1999;129:988–93.
7. Villar J, Belizan JM. The timing factor in the pathophysiology of the intrauterine growth retardation syndrome. Obstet Gynecol Surv 1982; 37:499–506.
8. Li R, Haas JD, Habicht J-P. Timing of the influence of maternal nutritional status during pregnancy on fetal growth. Am J Hum Biol 1998;10:529–39.
9. Scholl TO, Hediger ML, Ances IG, Belsky DH, Salmon RW. Weight gain during pregnancy in adolescence: predictive ability of early weight gain. Obstet Gynecol 1990;75:948–53.
10. Abrams B, Selvin S. Maternal weight gain pattern and birth weight. Obstet Gynecol 1995;86:163–9.
11. Brown JE, Jacobs DR Jr, Barosso GM, et al. Recruitment, retention and characteristics of women in a prospective study of preconceptual risks to reproductive outcomes. Experience of the Diana Project. Paediatr Perinat Epidemiol 1997;11:345–58.
12. Yu SM, Nagey DA. Validity of self-reported pregravid weight. Ann Epidemiol 1992;2:715–21.
13. Pirie P, Jacobs D, Jeffery R, Hannan P. Distortion in self-reported height and weight data. J Am Diet Assoc 1981;78:601–6.
14. To WW, Cheung W. The relationship between weight gain in pregnancy, birth-weight and postpartum weight retention. Aust N Z J Obstet Gynaecol 1998;38:176–9.