Original Article

Difference in ponderal growth and body composition among pregnant vs. never-pregnant adolescents varies by birth outcomes

Jee H. Rah*, Abu Ahmed Shamim†, Ummeh T. Arju†, Alain B. Labrique*,
Rolf D.W. Klemm*, Mahbubur Rashid† and Parul Christian*

*Center for Human Nutrition, Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland 21205, USA, and †JiVitA Maternal and Child Research Project, Rangpur 5400, Bangladesh

Abstract

Recently, we showed that following pregnancy and 6 months of lactation, adolescents cease linear growth and have reduced fat and lean mass in rural Bangladesh. Here, we examined whether these changes varied by pregnancy outcomes such as fetal loss, low birthweight (LBW) and neonatal mortality. Anthropometric measurements were taken among 12–19-year-old primigravidae ($n = 229$) in early pregnancy and at 6 months post-partum. Never-pregnant adolescents ($n = 456$) matched on age and time since menarche were also measured at the same time. Change in anthropometry among pregnant vs. never-pregnant adolescents was compared by pregnancy outcome adjusting for confounders using mixed effects regression models. Pregnant girls, irrespective of birth outcome, did not gain in stature, while never-pregnant girls increased in height by 0.36 ± 0.04 cm year⁻¹ ($P < 0.05$). Body mass index, mid-upper arm circumference (MUAC) and % body fat among pregnant adolescents whose infants survived the neonatal period had decreased at 6 months post-partum, whereas those who experienced a fetal loss or neonatal death did not change in any of the measurements. Consequently, the difference in change in ponderal size and body composition measures between pregnant and never-pregnant girls was higher among those whose neonates survived vs. those who experienced a fetal loss/neonatal death (BMI: -0.64 ± 0.11 vs. 0.01 ± 0.16 kg m⁻² year⁻¹; MUAC: -0.96 ± 0.12 vs. -0.35 ± 0.17 cm year⁻¹, both $P < 0.05$). LBW and preterm birth did not have a similar effect modification. Linear growth ceased among pregnant girls regardless of birth outcome. Maternal weight loss and depletion of fat and lean mass at 6 months post-partum were more pronounced when the infants survived through the neonatal period.

Keywords: linear growth, adolescent growth, adolescent pregnancy, body composition, lactation, pregnancy outcome.

Correspondence: Parul Christian, Johns Hopkins Bloomberg School of Public Health, 615 N. Wolfe Street, Room W2041, Baltimore, MD 21205, USA. E-mail: pchristi@jhsph.edu

Introduction

Early marriage and childbearing of adolescent girls is a serious reproductive health challenge in developing countries. Competition for limited nutrients between the growing teenage mother and her fetus may increase the risk of adverse birth outcomes such as preterm birth, low birthweight (LBW) and neonatal

mortality (Wallace *et al.* 1996; Wallace 2000; Wallace *et al.* 2001; Malamitsi-Puchner & Boutsikou 2006; Stewart *et al.* 2007).

In developed countries where food availability is not limiting, 'growing' adolescent mothers have been shown to attain greater gestational weight gain and weight retention in the post-partum period compared with adult women (Scholl *et al.* 1994). However, the

birthweight of the infant of growing teenagers was found to be significantly lower than that of adult women, indicating a preferential compartmentalization of nutrients to the growing mother during adolescent pregnancy (Scholl *et al.* 1994).

In contrast, adolescent girls in poor rural populations in developing countries are likely to be nutritionally compromised at conception and have low dietary intakes during pregnancy and lactation (Chaturvedi *et al.* 1996; Pathak *et al.* 2003). Consequently, in severely undernourished pregnant adolescents, maternal nutritional depletion and impaired growth of the fetus are likely to occur concurrently because of the competition for nutrients between the growing teenage mother and the fetus (King 2003). In fact, in a recent study, adolescent ewes that were undernourished during pregnancy exhibited lower maternal weight and fat mass throughout gestation compared with those who were fed optimal control diet (Luther *et al.* 2007). Fetal weight and fat mass of the undernourished ewes were significantly lower than that of the control group (Luther *et al.* 2007).

Recently, in a prospective cohort study of 12- to 19-year-old adolescent girls in an undernourished rural population in Bangladesh, we showed that pregnancy and lactation during adolescence can hamper post-menarcheal linear and ponderal growth (Rah *et al.* 2008). Per cent body fat, fat mass and muscle mass reduced significantly over a year's period among adolescents who had experienced pregnancy followed by 6 months of lactation, with deficits being greater in those who became pregnant after a short interval since menarche.

Here, we compare linear and ponderal growth and body compositional changes over the period of a year among pregnant vs. never-pregnant post-menarcheal

12–19-year-old girls in rural Bangladesh by type of pregnancy outcomes that are likely to reflect varying degrees of reproductive and lactational stress. Differences in annual changes in anthropometric measurements relative to that of never-pregnant girls were compared between adolescents: (1) whose infants survived throughout the neonatal period and those who experienced a fetal loss (miscarriage and stillbirth) or neonatal death; (2) who had normal birthweight infants and those who had LBW infants; and (3) who had preterm delivery and those who had term delivery. Differences in annual changes in anthropometric measurements relative to that of never-pregnant girls were also compared by frequency of lactation at 3 and 6 months post-partum.

Materials and methods

Study design and population

This study was carried out in the District of Gaibandha in rural northwest Bangladesh as part of a randomized controlled trial of the impact of weekly vitamin A and β -carotene supplementation on maternal and infant health and survival (called JiVitA Project). The JiVitA trial area was composed of 596 small communities covering a total population of ~580 000. Details of the study are described elsewhere (Rah *et al.* 2008). Briefly, in 96 of the 596 communities, a prospective cohort study was conducted from January 2005 to December 2006 among 12–19-year-old primigravidae ($n = 229$) and never-pregnant adolescents ($n = 456$) selected to be matched on age and time since menarche using a ratio of 1 : 2. First, 96 female project workers called Female Distributors conducted a census in the selected study area to

Key messages

- Pregnancy and lactation during adolescence ceased linear growth among girls in rural Bangladesh; this occurred irrespective of the type of birth outcome and survival status of the newborn.
- Ponderal size and body composition measures decreased but only among adolescents whose newborns survived, suggesting that a desirable infant outcome may occur at the cost of an adverse impact on adolescent nutritional status.
- There is an urgent need for boosting policies and programmes to reduce adolescent pregnancy in developing countries to prevent adolescent undernutrition, adulthood stunting and poor reproductive health.

enumerate all married and unmarried female adolescents. Information regarding the date of birth, month and year of menarche, marital status and pregnancy history was collected by interviewing the adolescent and her parents during the home visit. A total of 2605, married ($n = 385$) and unmarried ($n = 2220$), 12–19-year-old adolescents who were post-menarcheal and had never been pregnant before were identified.

All married adolescents were registered into the JiVitA pregnancy surveillance system, through which they were visited at home once every 5 weeks by Female Distributors who identified pregnancies by offering an human Chorionic Gonadotropin (hCG) urine-based test to those who were amenstrual in the previous month. Adolescents becoming pregnant for the first time were identified as part of this surveillance system. Each time a pregnant adolescent was identified, two never-pregnant adolescents of the same age (in years) and time since menarche (in months) were randomly selected from the pool of enumerated adolescents as part of the present study. After obtaining consent, pregnant adolescents were followed through pregnancy up to 6 months post-partum, and never-pregnant adolescents were concurrently followed for a similar time period, approximately a year.

Data collection

An enrolment interview was conducted in the home of the pregnant adolescents in approximately a week after being identified as pregnant to collect information on their dietary intake and physical work activity from the preceding week, morbidity in the past month, and smoking and alcohol consumption. Anthropometric measurements including height, weight, mid-upper arm circumference (MUAC), and triceps (TSF) and subscapular (SSF) skinfolds were taken. This baseline measurement was considered a proxy pre-pregnancy measurement because it occurred at a mean (SD) gestational age of 9.7 (2.8) weeks. Nineteen pregnant adolescents who were enrolled after 16 weeks of gestation were excluded because their baseline anthropometric measurements were less likely to be proxy for pre-pregnancy measurements. A 6-month post-partum visit was conducted to measure anthropometry and to conduct an

interview. Never-pregnant adolescents were also assessed at baseline and 12 months later: both visits were scheduled within a week of the assessments done in their pregnant counterparts.

Data on socio-economic status (SES) were collected at baseline in both groups. Birthweight was measured in the home of the pregnant adolescents using a digital infant scale (Tanita Model 1583 Baby Scale, Tokyo, Japan) at a mean (SD) of 16 (± 10) h within birth. Pregnant girls enrolled into the trial were visited by a Female Distributor once a week for supplementation from the time of pregnancy ascertainment through 3 months post-partum. During these visits, they also recorded birth outcomes and deaths. Each time a miscarriage or stillbirth was reported, a trained female interviewer performed a home-based interview to elicit the history related to the event. The vital status of all the infants was assessed every week through 3 months of age and at 6 months of age. Information on breastfeeding practices was collected at the 3 and 6-month post-partum visits inquiring whether they were still breastfeeding and about the frequency of breastfeeding in the past 24 h.

All interviews and measurements were conducted by eight female interviewers/anthropometrists who were trained and standardized at the start of the study. Standardization was accomplished with each female interviewer measuring a group of 10–15 women twice with an hour between measurements, which was repeated every 3 months throughout the data collection period. Both intra- and inter-observer reliability were assessed by calculating the technical error of measurement (TEM) (Ulijaszek & Kerr 1999). The TEM of female anthropometrists was maintained at approximately half the cut-off of suggested acceptable TEM values throughout the study (Shorr 1986; Rah *et al.* 2008). Anthropometric measurements were taken following recommendations (Gibson 1990). Height was measured using a Harpenden stadiometer (Shorr Productions, Woonsocket, RI, USA) accurate to 0.1 cm, and weight was taken using a digital scale (UNICEF scale S0141015 by SECA Ltd, Birmingham, UK) accurate to 0.1 kg. Skinfolds were recorded to the nearest 0.2 mm using Holtain calipers (Holtain Ltd, Dyfed,

Wales, UK) and MUAC to the nearest 0.1 cm using a non-stretch locally manufactured insertion tape based on the Ross non-elastic tape (Ross Laboratories, Columbus, OH, USA). All measurements except weight were taken three times, and the median value for each measurement was used.

Statistical analyses

BMI (weight/height²) was calculated using weight and height. Estimates of upper arm muscle and fat areas were calculated using MUAC and TSF, and per cent body fat using TSF and SSF following the previously described procedures (Slaughter *et al.* 1988; Frisnacho 1990). Stunting and underweight were defined as a height-for-age and weight-for-age Z-score of less than -2, respectively, of the Center for Disease Control (CDC 2002) reference standards (Atlanta, GA, USA). Gestational age was calculated from the first date of last menstrual period collected at the baseline interview, which was checked against the prospectively collected menstrual histories. Miscarriage and stillbirth were defined as a fetal loss before, and at or after 28 weeks of gestation, respectively. Five pregnant adolescents who had induced abortion were included in the present analysis because they were comparable to adolescents who had spontaneous abortion on their baseline characteristics, and the results of the analysis did not differ by excluding them. Neonatal mortality was defined as deaths among live births during the first 28 days of life. Only birthweight taken within 72 h of birth was used in the present analysis. LBW was defined as <2.5 kg and preterm birth was defined as birth before 37 weeks of gestation.

Data on SES status were classified into dwelling characteristics, land ownership, productive and durable assets, and human capital. A composite variable called 'wealth index' was developed based on these categories (S. Gunnsteinsson *et al.* 'unpublished data') using a principal components analysis (Vyas & Kumaranayake 2006).

Change in anthropometric measurements between baseline and the 12-month follow-up was calculated by dividing the difference by the number of days between the baseline and follow-up measurements,

which was then annualized. Differences in annual changes in anthropometric measurements between pregnant and never-pregnant adolescents were compared by outcome of pregnancy and frequency of lactation using analysis of variance. Pregnancy outcomes were dichotomized as follows: those experiencing miscarriage, stillbirth or neonatal death vs. live birth with infant surviving the neonatal period; LBW vs. normal birthweight; preterm vs. term delivery. There were no differences in annual changes in anthropometric measurements between adolescents who had a miscarriage and those who experienced stillbirth or neonatal death except in weight and BMI. Thus, adolescents who had a miscarriage, stillbirth and neonatal death were combined into a single category because of the small sample size for each outcome. Frequency of breastfeeding at 3 and 6 months post-partum was dichotomized using the median as a cut-off.

The linear mixed effects regression models were fitted to compare changes in anthropometric measurements over time by pregnancy outcome and frequency of breastfeeding adjusting for potential confounders (Brown *et al.* 2006; Finucane *et al.* 2007). Anthropometric measurements were included as dependent variables with separate models constructed for each outcome of interest including height, weight, BMI, MUAC, TSF, SSF, upper-arm muscle and fat area, and per cent body fat. Independent variables included birth outcome or frequency of lactation, time of measurement in years since the baseline visit, interaction between time and birth outcome/frequency of lactation, and potential confounders. Dummy variables of birth outcome and frequency of lactation were created with never-pregnant girls forming the reference group. Confounding factors were variables that differed by pregnancy outcome and status at the baseline and 12-month follow-up and were associated with annual change in each anthropometric measurement in the bivariate analyses ($P < 0.05$). Age and time since menarche were included in the models, regardless of statistical significance. The robust estimates of standard errors were computed. The interaction between time and birth outcome/frequency of lactation reflected the difference in annual changes in anthropometry relative

Fig. 1. Study participation and follow-up among pregnant and never-pregnant adolescents, and birth outcome.

to that of never-pregnant girls by birth outcome/frequency of lactation. All analyses were performed using STATA version 8.0 (Stata Corp, College Station, TX, USA).

The study was approved by the Bangladesh Medical Research Council, Dhaka, Bangladesh and the Institutional Review Board at the Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA.

Results

Study participation, follow-up and pregnancy outcomes

Out of 210 pregnant adolescents who were enrolled within 16 weeks of gestation, 199 (94.8%) completed the baseline and 6-month post-partum assessments (Fig. 1). Of these, 37 (19%) had a miscarriage or stillbirth, and 162 (81%) had a live birth among which 29 (18%) were preterm and 13 (8%) died during the neonatal period (Fig. 1). Birthweight was measured within 72 h among 101 (62%) live born infants of which 55 (54%) were born with LBW. Those who

refused to participate in the study or were lost to follow-up because of migration or pregnancy were comparable to the rest of the girls in baseline characteristics (data not shown).

Baseline characteristics of adolescents by birth outcome

The baseline mean (SD) age and age at menarche of all the adolescent girls combined was 16.3 (1.6) years and 12.7 (1.2) years, respectively. Except for the prevalence of stunting (40% vs. 58%, $P < 0.05$), there were no differences in baseline characteristics between adolescents who had fetal loss or neonatal death and those whose infants survived through the neonatal period (Table 1). Adolescents who had LBW infants were younger, shorter and weighed less than those who had normal birthweight infants (16.2 ± 1.6 vs. 16.8 ± 1.5 years; 147.8 ± 4.5 vs. 151.9 ± 5.6 cm; 42.1 ± 4.4 vs. 45.1 ± 4.4 kg, all $P < 0.05$). A higher proportion of adolescents who had normal birthweight vs. those who had LBW infants came from families with higher SES status (48 vs. 26%, $P < 0.05$). Adolescents who had preterm

Table 1. Baseline characteristics of never-pregnant and pregnant adolescents by outcome of pregnancy

	Never-pregnant adolescents (<i>n</i> = 385)	Pregnant adolescents [mean (SD)]			
		Fetal vital status		Birthweight	
		Fetal loss/neonatal death (<i>n</i> = 50)	Live birth/neonates alive (<i>n</i> = 149)	Low (<i>n</i> = 55)	Normal (<i>n</i> = 46)
Chronological age (years)	16.3 (1.6)	16.2 (1.9)	16.4 (1.5)	16.2 (1.6) [§]	16.8 (1.5)
Age at menarche (years)	12.7 (1.2)	12.5 (1.2)	12.8 (1.2)	12.9 (1.1)	12.9 (1.1)
Time since menarche (months)	43.0 (20.0)	43.2 (23.8)	43.1 (19.9)	39.8 (17.3)	45.6 (20.1)
Baseline anthropometry					
Height (cm)	149.4 (5.1)	149.5 (4.8)	149.3 (5.4)	147.8 (4.5) [§]	151.9 (5.6)
Weight (kg)	42.4 (5.5)	42.2 (4.7)	43.1 (5.0)	42.1 (4.4) [§]	45.1 (4.4)
BMI (kg m ⁻²)	19.0 (2.0)	19.0 (1.7)	19.3 (1.7)	19.2 (1.6)	19.5 (1.6)
Stunting (%) [*]	47.0	40.0 [†]	57.7	67.4 [‡]	39.1
Underweight (%) [*]	40.1	42.0	40.9	47.3 [‡]	23.9
Socio-economic (SES) status indicators					
Literate (%)	87.3 [‡]	78.0	73.2	70.9	73.9
Highest grade completed (>5th grade) (%)	83.6 [‡]	58.0	67.8	70.9	63.0
Income-earning job (%)	14.3 [‡]	24.0	25.5	25.5	39.1
Religion					
Muslim (%)	84.4 [‡]	94.0	91.3	92.7	89.1
Hindu (%)	15.1 [‡]	6.0	7.4	5.5	8.7
Other (%)	0.5	0	1.3	1.8	2.2
Wealth index score (>0.5) [‡]	57.1 [‡]	35.1	38.3	25.5 [¶]	47.8

^{*}Stunting and underweight were defined as height-for-age and weight-for-age Z-scores less than -2, respectively; [†]Adolescents with wealth index score >0.5 are from higher SES; [‡]Different from pregnant adolescents with *P* < 0.05 using a chi-square test; [§]Different from adolescents who had fetal loss or normal birthweight infants with *P* < 0.05 using a *t*-test; [¶]Different from adolescents who had fetal loss or normal birthweight infants with *P* < 0.05 using a chi-square test.

delivery or neonatal death were comparable to those who did not have such adverse outcomes with respect to baseline characteristics (data not shown). There were no differences in baseline dietary intake, physical work activity and morbidity by outcome of pregnancy (data not shown).

Annual changes in anthropometric measurements by birth outcome

Pregnant girls, irrespective of birth outcome, experienced no height gain, while never-pregnant girls increased in stature by 0.35 ± 0.04 cm year⁻¹, adjusting for confounders (Table 2). On the other hand, adolescents whose infants survived the neonatal period had lower weight, BMI, MUAC, upper arm muscle area and per cent body fat by 6 months postpartum, whereas those who experienced a fetal loss or neonatal death did not decrease in any of these measurements over the period of a year (all *P* < 0.05).

Thus, the difference in annual change in ponderal and body compositional measurements between pregnant and never-pregnant girls was higher among the neonatal survivors compared with those who had a fetal loss or neonatal death (all *P* < 0.05) (Table 2). The annual changes in anthropometric measurements did not differ between adolescents who had a preterm delivery and those who had a term delivery, and between adolescents who had LBW infants and those who had normal birthweight infants (Table 2).

Annual changes in anthropometric measurements by frequency of lactation

All (100%) pregnant girls whose infants were alive reported breastfeeding at both 3 and 6 months postpartum. The median (interquartile range) frequency of breastfeeding in the past 24 h was 12 (10–15) and 11 (9–14) times among those who were able to recall the information at 3 (*n* = 68, 46%) and 6 months

Table 2. Adjusted mean (SE) annual changes in anthropometric measurements relative to that of never-pregnant (NP) adolescents by outcome of pregnancy

		NP (<i>n</i> = 385)	Pregnancy outcomes [mean (SE)]			
			Fetal vital status		Birthweight	
			Fetal loss/neonatal death (<i>n</i> = 50)	Live birth/neonates alive (<i>n</i> = 149)	Low (<i>n</i> = 55)	Normal (<i>n</i> = 46)
Height (cm)	Annual change	0.35 (0.04) [‡]	−0.11 (0.13) [‡]	−0.06 (0.08) [‡]	0.01 (0.12) [‡]	−0.05 (0.14) [‡]
	Difference*	−	−0.45 (0.13)	−0.41 (0.09)	−0.35 (0.14)	−0.41 (0.15)
Weight (kg)	Annual change	0.97 (0.13) [‡]	0.82 (0.44)	−0.94 (0.21) ^{‡,‡}	−0.81 (0.34) [‡]	−0.79 (0.36) [‡]
	Difference	−	−0.15 (0.46)	−1.91 (0.24) [§]	−1.74 (0.37)	−1.72 (0.39)
BMI (kg m ^{−2})	Annual change	0.34 (0.06) [‡]	0.32 (0.19)	−0.41 (0.09) ^{‡,‡}	−0.35 (0.15) [‡]	−0.31 (0.15) [‡]
	Difference	−	−0.01 (0.20)	−0.74 (0.10) [§]	−0.67 (0.16)	−0.63 (0.17)
MUAC (cm)	Annual change	0.30 (0.06) [‡]	−0.18 (0.18) [‡]	−0.78 (0.10) ^{‡,‡}	−0.61 (0.15) [‡]	−0.65 (0.16) [‡]
	Difference	−	−0.48 (0.19)	−1.08 (0.11) [§]	−0.91 (0.17)	−0.95 (0.18)
TSF (mm)	Annual change	−0.17 (0.12)	−0.66 (0.34)	−1.72 (0.16) ^{‡,‡}	−1.66 (0.29) [‡]	−2.05 (0.31) [‡]
	Difference	−	−0.49 (0.36)	−1.55 (0.20) [§]	−1.51 (0.32)	−1.91 (0.33)
SSF (mm)	Annual change	0.64 (0.10) [‡]	0.19 (0.24)	−0.03 (0.14) [‡]	0.24 (0.26)	−0.10 (0.30)
	Difference	−	−0.45 (0.26)	−0.67 (0.17)	−0.35 (0.29)	−0.69 (0.30)
Upper-arm muscle area (cm ²)	Annual change	1.07 (0.13) [‡]	0.15 (0.41) [‡]	−0.72 (0.23) ^{‡,‡}	−0.20 (0.11) [‡]	0.13 (0.40) [‡]
	Difference	−	−0.93 (0.43)	−1.79 (0.26)	−1.24 (0.40)	−0.91 (0.43)
% body fat	Annual change	0.30 ± (0.13) [‡]	−0.43 (0.41)	−1.42 (0.20) ^{‡,‡}	−1.19 (0.34) [‡]	−1.77 (0.36) [‡]
	Difference	−	−0.73 (0.43)	−1.72 (0.23) [§]	−1.48 (0.37)	−2.06 (0.38)

MUAC, mid-upper arm circumference; TSF, tricep skinfold; SSF, subscapular skinfold; *Difference in annual change in anthropometric measurements compared with that of NP adolescents; [†]Adjusted annual change being statistically significant with $P < 0.05$ using mixed effects regression models; [‡]Different from NP adolescents with $P < 0.05$ using mixed effects regression models adjusting for age, time since menarche, wealth index, morbidity, dietary intake and physical activity; [§]Different from adolescents who had fetal loss or neonatal death with $P < 0.05$ using mixed effects regression models adjusting for age, time since menarche, wealth index, morbidity, dietary intake and physical activity.

($n = 85$, 58%) post-partum, respectively. Using the median as the cut-off, annual change in anthropometric measurements among pregnant vs. never-pregnant girls did not differ by frequency of breastfeeding at 3 (BMI: -0.84 ± 0.20 vs. -0.92 ± 0.17 kg m^{−2} year^{−1}, $P = 0.73$) and 6 months post-partum (BMI: -0.60 ± 0.18 vs. -0.74 ± 0.15 kg m^{−2} year^{−1}, $P = 0.51$).

Discussion

In the present analysis, we examined whether the linear and ponderal growth, and body composition of post-menarcheal girls differed by birth outcomes including fetal and early infant loss, LBW and preterm delivery. This was done using the data collected from a cohort study in rural Bangladesh, which recently demonstrated that pregnancy and lactation during adolescence ceased linear growth and resulted in depletion of fat and lean mass of young mothers (Rah *et al.* 2008). In this paper, we reported that ces-

sation of linear growth occurred in all adolescents at 6 months post-partum following a pregnancy, regardless of birth outcome or infant vital status. However, adolescents whose infants survived through the neonatal period had lower ponderal and body compositional measures by 6 months post-partum. On the other hand, those who experienced a fetal or early infant loss gained weight and lean mass and had lower reductions in body fat measures at 6 months post-partum. Annual changes in anthropometric measurements did not differ between adolescents who had normal birthweight infants and those who had LBW infants, preterm and term delivery, and who breastfed <11 and ≥ 11 times per day at 6 months.

To our knowledge, the present study was the first attempt to document the differential pattern of change in linear and ponderal size, and body composition of teenage mothers by pregnancy outcome. Our longitudinal data permitted this type of analysis in a poor undernourished rural population where marriage and

pregnancy occur early, and adverse birth outcomes are prevalent.

As shown in previous studies mostly involving adult subjects, adolescents who had LBW infants were found to be shorter and weigh less at baseline than those who had normal birthweight infants (Johnson *et al.* 1994; Murakami *et al.* 2005; Ogbonna *et al.* 2007). This implies that poor maternal nutritional status in early gestation is likely to be predictive of reduced birthweight of infants among adolescent girls in rural Bangladesh. Adolescents who experienced fetal or early infant loss and neonatal deaths did not differ from those whose neonates survived in terms of demographic, anthropometric and other characteristics. Kristensen *et al.* also reported no significantly increased risk of stillbirth or neonatal death among underweight women, although the study was done in adult subjects in a developed country (Kristensen *et al.* 2005). However, the previous observation of underweight or thin women having an increased risk of preterm delivery was not shown in the present study (Chang *et al.* 2003; Hauger *et al.* 2008).

Adolescents failed to gain height once they became pregnant, a phenomenon that remained unaffected by the duration of pregnancy or type of birth outcome. A potential underlying mechanism explaining this complete cessation of linear growth may be that linear growth is more sensitive to nutrient supply. Alternatively, the acceleration of epiphyseal closure due to the increased estrogen concentration during pregnancy may cause such an effect (Vander *et al.* 1998). The latter explanation is more likely because linear growth halted even among adolescents whose pregnancies terminated early as a result of either spontaneous or induced abortion.

Weight loss, and reduced fat and lean mass of adolescent whose infants survived through the neonatal period are indicative of depletion of maternal energy and nutrient reserves to meet the demands of pregnancy and lactation. Conversely, evidence from well-nourished teenagers in developed countries has shown a large gestational weight gain and postpartum weight retention, and continuing accrual of fat mass during late pregnancy through early postpartum (Scholl *et al.* 1994; Hediger *et al.* 1997). In

developing countries, poor pre-pregnancy nutritional status, coupled with inadequate nutrient intake during pregnancy and lactation, is likely to aggravate the depletion of maternal nutritional stores (Adair & Popkin 1992; King 2003).

When the duration of pregnancy and lactation was reduced because of fetal loss or neonatal death, the magnitude of maternal weight and fat loss was strikingly less, suggesting a nutrient partitioning to support growth of the young mother rather than the fetus. Alternatively, a shorter duration of nutritional stress due to the death of the fetus or infant may have spared the nutritional reserves of the mother. Our research can not distinguish whether preferential channelling to the mother may have in fact caused the fetal loss or neonatal death.

However, we also compared changes in anthropometric measurements between adolescents who had an early miscarriage (either spontaneous or induced) and those who experienced a stillbirth or neonatal death. Adolescents who had a miscarriage gained in weight and BMI, whereas those who had stillbirth or neonatal death slightly declined in both measures over the period of a year. This seems to suggest that the preferential partitioning of nutrients to the mother and consequent adverse birth outcome may not have occurred in this context. Rather, the nutritional demands on the mother were driven by the length of the intrauterine period and duration of lactation.

The higher energy and protein requirement of lactation poses a higher nutritional burden than pregnancy to the mother (Institute of Medicine 1991). The negative change in maternal nutrient reserves during lactation has been demonstrated in other developing countries, with depletion being more pronounced as the duration of breastfeeding increased (Adair & Popkin 1992). This association has been explained by the increased nutritional demands imposed by lactation and the role of lactation-induced hormones in mobilization of maternal energy reserves (Adair & Popkin 1992). Unfortunately, we were limited by the data collected on lactation in our study. We collected information only on the frequency of lactation, which may not be a precise measure of burden of lactation. Also, only 46% and 58% of adolescents were able to

recall the frequency of breastfeeding during the past 24 h at 3 and 6 months post-partum, respectively. These may explain the lack of difference in annual change in maternal anthropometric measurements by frequency of lactation in the present study.

A few limitations to this study need to be considered. It has been suggested that maternal depletion needs to be evaluated over a full reproductive cycle (Winkvist *et al.* 1992). In this study, pregnant adolescents were followed up to 6 months post-partum when the majority of the girls who had live births were still engaged in full or partial lactation. Thus, the negative change in ponderal size and body composition observed in our data may not be strictly defined as maternal depletion because a complete repletion in maternal nutritional status can occur during the non-pregnancy/non-lactation phase. Stillbirth ($n = 12$) and neonatal death ($n = 13$) were combined as a single category because of the small sample size for each outcome. Birthweight was measured within 72 h of birth only among 62% of live born infants. Thus, the possibility of lack of statistical power must be considered in interpreting our results, indicating no differences in anthropometric changes by birthweight and size of birth. In addition, we were unable to specifically tease out pregnancy vs. lactation as exposures because of the lack of data on maternal nutritional status at the end of gestation and immediate post-partum period. There may be food beliefs in pregnancy such as avoiding certain foods or food prescriptions/proscriptions that were not considered when describing the changes in nutritional status of the pregnant women. The current findings may not be generalizable to young mothers in developed countries who are likely to be better nourished prior to conception and during pregnancy and lactation, in part because of lack of maternal dietary restrictions commonly practised in developing country settings.

In conclusion, this study revealed the differential changes in ponderal size and body composition during pregnancy and lactation by birth outcome among rural Bangladeshi adolescent girls. The most unfavourable consequence of pregnancy and lactation on maternal nutritional status was observed among adolescents who had the most desirable birth outcome. Pregnancy and lactation during adolescence

ceased the linear growth of young girls regardless of their birth outcome, which may increase the risk of adulthood stunting and obstructed labor in successive pregnancies. Efforts to reduce premature pregnancy are needed in developing countries not only to improve infant health and survival but also to enhance the nutritional status of young mothers, and to cease the intergenerational vicious cycle of under-nutrition. Nutritional interventions prior to, and during, pregnancy may help reduce the depletion of maternal energy reserves and lean body mass.

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Conflicts of Interest

None declared.

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