

ORIGINAL COMMUNICATION

Associations between reproduction and maternal body weight: examining the component parts of a full reproductive cycle

A Winkvist^{1*}, KM Rasmussen² and L Lissner³

¹Epidemiology, Department of Public Health and Clinical Medicine, Umeå University, Umeå, Sweden; ²Division of Nutritional Sciences, Cornell University, Ithaca, New York, USA; and ³Department of Primary Health Care, Göteborg University and Nordic School of Public Health, Gothenburg, Sweden

Objective: Many transitional societies currently face both extremes of nutritional status, undernutrition and overnutrition. Women of reproductive age are at high risk of these conditions. The purpose of this review is to consider evidence for relationships between reproduction and nutritional status in women from societies of varying economic development, using body weight or weight-for-height as indicators of maternal nutritional status.

Design: The conceptual framework guiding this review is that the duration of the reproductive cycle varies as a function of its component parts, which include (i) pregnancy, (ii) lactation, (iii) the non-pregnant/non-lactating (NP/NL) interval or, possibly, (iv) an overlap between lactation and next pregnancy. All component parts of the complete cycle vary in length and are associated with changes in nutritional status. A variety of factors ('proximal and distal determinants') influence the duration of the component parts of the reproductive cycle. This framework is used to examine current knowledge of changes in maternal nutritional status during each of these parts.

Results: Women in affluent societies retain some weight with each pregnancy, beyond that of non-pregnant women. Women in less affluent societies retain less weight with each pregnancy. During lactation, women in both affluent and less affluent societies experience only modest weight loss. During the NP/NL interval, women in affluent societies tend to gain weight, whereas weight of women in less affluent societies is likely to fluctuate.

Conclusions: We conclude that there is a dearth of information on certain parts of the cycle, particularly the periods of overlap of lactation with pregnancy and the NP/NL interval.

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Introduction

Nutritional status of women is important for the health and work capacity of women themselves as well as for the health of their offspring. Unfortunately, problems of under- as well as overnutrition prevail in female populations worldwide. For example, the proportion of women suffering from chronic energy deficiency (body mass index (BMI)

< 18.5 kg/m²) is about 70% in India, Bangladesh and Pakistan (ACC/SCN, 1998). For Africa, this proportion is 20–40%. There is evidence that women are more likely than men to suffer undernutrition in some of these regions (eg South Asia), in part because of burdens of reproduction and social conditions in general (Leslie, 1991). In some regions (eg Africa), rates of undernutrition have increased during recent decades as a result of economic and political turmoil. Concern has been raised that babies born to undernourished women have a higher risk of developing chronic diseases during adulthood than babies born to better nourished women (Stein *et al*, 1996). At present, however, evidence is lacking to support a link between poor maternal nutritional status and the determinants or consequences of chronic disease in the offspring of such women as children or as adults (Rasmussen, 2001).

*Correspondence: A Winkvist, Epidemiology, Department of Public Health and Clinical Medicine, Umeå University, 901 85, Umeå, Sweden. E-mail: anna.winkvist@epiph.umu.se

Guarantor: A Winkvist.

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Concurrently, in many parts of the world, increasing prevalences of obesity (BMI ≥ 30) have been documented especially among women. For instance, obesity is at least three times more prevalent among women compared to men in several African nations (WHO, 2000). In Brazil the prevalence of obesity is approximately twice as high among women as among men. In China the rates are only 1.2% in men and 1.6% in women (although rates are rapidly increasing and urban areas have higher rates than rural areas), in contrast to urban Samoa where 58% men and 77% women are obese. The pattern of gender differences is mixed in Europe, with some indications (eg former East Germany and Finland) that prevalences may be increasing faster among men than women. In recent US surveys, the highest rates of obesity are consistently observed among African American women and other female minority populations.

As documented by the WHO (2000), the traditional geographic split between areas of over- and undernutrition has become obscured as a consequence of the rapidly occurring 'nutrition transition'. This phenomenon, which refers to the shift from a high prevalence of underweight to a high prevalence of overweight in populations undergoing modernization, is a topic of increasing public health concern (Popkin, 1994). However, it has only recently been recognized that obesity and related co-morbidities in less affluent societies represent one of the largest epidemics currently faced by health-care systems. There is evidence from a number of less-affluent societies (eg Brazil) that obesity is increasing faster among low-income, urban women than among women from middle and higher socioeconomic classes (Popkin, 1994). Although rates of underweight are generally decreasing as overweight increases, in most underdeveloped areas overnutrition continues to co-exist with significant amounts of undernutrition (WHO, 2000). Thus, women in transitional societies now face both extremes of nutritional problems: high risks of being under- or overweight.

Reproduction has been identified as a possible cause of undernutrition among women in less affluent societies. The process, referred to as 'maternal depletion' (Winkvist *et al*, 1992), includes complex interactions between maternal and infant nutritional needs, in relation to initial maternal nutritional status (Winkvist *et al*, 1994, 1998). Meanwhile, in affluent societies, weight gain during reproduction has been considered, often anecdotally, a possible cause of female obesity. Still, reproduction alone cannot explain the obesity epidemic, which is affecting male as well as female populations.

In this paper, we provide a comprehensive review of the evidence for a relationship between reproduction and maternal nutritional status (referred to as MNS) in societies of varying economic development. Recently, we reviewed the effect of lactation on MNS among women in affluent and less affluent societies (Winkvist & Rasmussen, 1999). Our conceptual framework included the effects of duration and intensity of lactation on MNS as well as modifying effects

of intermediate factors on these associations. Here, we extend this framework to the full reproductive cycle (ie the period from one conception to the next; usually approximated as the period from one birth to the next because date of conception is difficult to obtain), considering many of the same intermediate factors that may modify effects on MNS during all parts of the cycle. In this review, we will focus on changes in maternal body weight as a general nutritional indicator, because this is the most extensively studied indicator of MNS. Our review is constrained by the available data, which include few longitudinal investigations and few of these provide comparisons with groups of women who are not reproducing.

Description of the conceptual framework

We developed five conceptual frameworks to guide this review: an overall view of determinants of MNS across the entire reproductive cycle (Figure 1) as well as a more detailed examination of each component part of the reproductive cycle, ie pregnancy (Figure 2), lactation (Figure 3), the non-pregnant/non-lactating (NP/NL) interval (Figure 4) and, finally, overlap of lactation with next pregnancy (Figure 5).

The duration of the reproductive cycle is a function of the duration of its component parts (Figure 1). The interval of the cycle is long enough to be associated with change in nutritional status even among non-pregnant women. Thus, the change that is attributable to reproductive events can only be known in comparison to change over the same time among women without these events. However, women who never conceive may differ systematically from women who conceive, which may make them an unsuitable comparison group (see below). Further, a variety of factors ('proximal and distal determinants') influence the duration of the component parts of the reproductive cycle. For example, medical factors may be associated with preterm birth, psychosocial factors may be associated with a shortened duration of breastfeeding or sociocultural factors may be associated with desired contraceptive use, which influence the duration of the NP/NL interval. These 'proximal and distal determinants' may also influence the intermediate factors illustrated in Figures 2–5 that modify the effects of duration of each

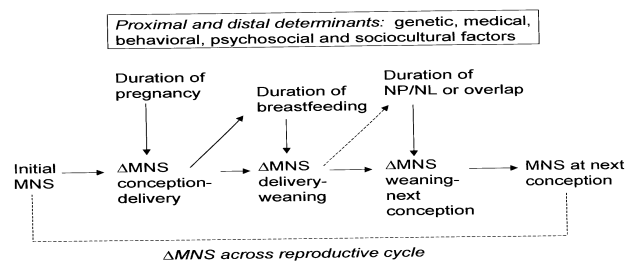


Figure 1 Component parts of changes in maternal nutritional status (Δ MNS) across a reproductive cycle, and major groups of factors affecting the change.

component part on MNS. For example, seasonal factors (eg food availability and agricultural labour) may influence both dietary intake and physical activity during any of these component parts.

In our conceptual framework, we show that the change in MNS during pregnancy is, first of all, a function of the duration of gestation (Figure 2). This is most likely nonlinear, as the composition of the changes in maternal body composition varies as pregnancy progresses. In addition, if pregnancy terminates early because of maternal or foetal pathology, it is possible that this pathology may also have affected the net change in MNS during this period. Further, a number of the determinants of weight gain during pregnancy are also determinants of the duration of pregnancy (eg cigarette smoking, exercise, prepregnant BMI and some kinds of illness). The 'proximal and distal determinants' most likely influence these determinants of weight gain as well as dietary intake and maternal prepregnant BMI. In addition, weight (and weight gain) at any stage of gestation includes the size of the foetus. Our review will not discuss the interplay between foetal size and weight gain further.

The change in MNS that occurs during lactation is also complex (Figure 3). Both cigarette smoking and high as well as low maternal BMI are associated with shorter duration of breastfeeding and, thus, less change in MNS. In addition, the 'proximal and distal determinants' may affect the desired duration of breastfeeding (eg short maternity leave).

The change in MNS that occurs during NP/NL (Figure 4) depends largely on how long this period is, as it potentially has the greatest variability in duration of the four component parts. Maternal BMI may be a determinant of the NP/NL duration only among women who do not use contraceptives; it may be the longest among the women with the poorest nutritional status. Finally, we consider overlap of lactation with next pregnancy (Figure 5). The considerations here are the same as during the NP/NL period except that smoking may modify the relationship between the duration of overlap and change in MNS by causing preterm birth and shortening this interval.

Change in MNS during pregnancy in affluent societies

Women in affluent societies often complain that their excess weight in mid-life originated with a particular pregnancy. There are data to support this idea. For example, 73% of the severely obese women in the Stockholm Pregnancy and Weight Development Study had retained more than 10 kg in connection with a pregnancy (Rössner & Öhlin, 1995). Excess weight gain in the first pregnancy in particular has been associated with the development of obesity (Hunt *et al*, 1995).

However, population-based data suggest that major weight retention after pregnancy may be less common than is popularly believed. The available literature before 1990 reported a weight gain of 1 kg/pregnancy above that

expected during non-pregnant periods (Institute of Medicine 1990). More recent studies that meet criteria for satisfactory methodology show that mothers gain 0.9–3.3 kg more weight following pregnancy and retain 0.4–3.0 kg more weight than non-pregnant women during the same period of time (Harris & Ellison, 1997). (Weight changes of non-pregnant women are further discussed in the NP/NL section.) Pregnancy-related weight gain may be modified by sociodemographic and behavioural factors such as race, employment status, cigarette smoking and recreational exercise (Wolfe *et al*, 1997). It is likely that genetic factors may play an important role in pregnancy-related weight gain for some women, although little is known about genetic susceptibility to the development of obesity specifically during the reproductive period.

Most women in affluent societies end pregnancy heavier and fatter than they were at conception (Soltani & Fraser, 2000). The net gain in maternal body fat from week 12 of pregnancy until 2 weeks postpartum has been estimated to be 1.3 kg and the gain of fat-free mass to be 1.0 kg (Durnin, 1992). Net fat gain from before pregnancy until after delivery has been estimated as 5.7 kg and fat-free mass as 0.7 kg (Sadurskis *et al*, 1988). For newborns of similar size, the more women gain during pregnancy, the more they retain immediately after delivery (Greene *et al*, 1988; Schauburger *et al*, 1992), as most of the remaining variation in weight gain is not the other products of conception but rather maternal fat. There is some evidence that postpartum weight retention (net weight gain) is affected by the pattern of weight gain during pregnancy; weight gain before 20 weeks of gestation has been observed to be more strongly correlated with weight retention than weight gain later in gestation or total gain (Muscati *et al*, 1996). As one might expect (but few have measured), dietary intake during pregnancy is associated with subsequent fat accretion (Langhoff-Roos *et al*, 1987).

Competition for energy and nutrients

Although both excessive exercise and certain types of maternal illness during pregnancy may modify the change in MNS that is characteristic of pregnancy, both of these situations are rare. A common example of competition for nutrients occurs during adolescent pregnancy. Adolescents need to gain more weight to have a baby of the same size as adult women (Institute of Medicine, 1990). How the adolescent's body composition changes during pregnancy depends on whether she is still growing (Scholl *et al*, 1994). For example, black teens who had completed their growth experienced changes in body fatness that were similar to non-adolescent, mature women (ie a net loss between week 28 of pregnancy to 4–6 weeks postpartum). In contrast, those who were still growing gained body fat during this same period. Growing teens also gained more weight during pregnancy and retained more weight postpartum than non-growing teens and mature women (Scholl *et al*, 1994). In this same group of

black adolescents, the more weight they gained during pregnancy (irrespective of whether they were still growing themselves), the more they retained at 6 months postpartum (Scholl & Hediger, 1995). As is the case for mature women, this excess weight was primarily fat.

Prepregnant BMI

A woman's nutritional status at conception may modify not only the course of pregnancy and its outcome but also the way her nutritional status changes during pregnancy. In its most recent recommendations, the Institute of Medicine encouraged underweight American women to gain more than the 12.5 kg previously recommended and overweight and obese women to gain less than normal-weight women (Institute of Medicine, 1990). Reports vary about whether underweight women are at excess risk of shortened gestation (Naeye, 1990, Siega-Riz *et al*, 1996; Lumme *et al*, 1995; Cnattingius *et al*, 1998). They are not at excess risk of low weight gain independent of the duration of gestation (Edwards *et al*, 1978; Abrams & Laros, 1986; Caulfield *et al*, 1996). Obese women are at excess risk for both shortened and prolonged gestation (Gross *et al*, 1980; Baeten *et al*, 2001) and low or inadequate weight gain (or even weight loss) independent of the duration of gestation (Gross *et al*, 1980). Fat gain during pregnancy is affected by prepregnant BMI; underweight women retain more fat than normal or overweight women who, in turn, retain more fat than obese women (Lederman *et al*, 1997). Others have observed that overweight women tend to gain little fat in pregnancy but greater than average amounts of body water (Hytten, 1991). These observations may be explained by the positive relationship that has been observed between fat mass and basal metabolic rate during pregnancy (Bronstein *et al*, 1996).

Smoking

Smoking rates among women in affluent societies range from 14.8% in Japan to 37% in Denmark (WHO, 1997); an estimated 28% of American women of reproductive age smoke (Ebrahim *et al*, 2000). Smoking rates among pregnant women are lower, for example, only 11.8% of pregnant American women smoke according to recent data (Ebrahim *et al*, 2000). Nonetheless, smoking is associated with the largest aetiologic fraction of intrauterine growth retardation in less affluent societies (Kramer, 1998) and with a modest increase in the risk of preterm birth (Savitz & Pastore, 1999; Centers for Disease Control, 2001). Smokers gain less weight during pregnancy than non-smokers (Institute of Medicine, 1990; Rasmussen & Abrams, 1997). This is only one route by which smoking reduces foetal growth; smokers appear to have higher nutrient needs and also to consume less healthful diets than non-smokers (Rasmussen & Abrams, 1997; Dallongeville *et al*, 1998).

Change in MNS during pregnancy in less affluent societies

Pregnancy produces smaller changes in body composition among women in less affluent societies primarily because they gain so much less weight during pregnancy (7.3–8.5 kg in Gambia, Thailand and the Philippines compared with 10.5–11.7 kg in Scotland and The Netherlands) and, as a result, gain and retain less fat (0.6–1.4 kg in Gambia, Thailand and the Philippines compared with 2.0–2.3 kg in Scotland and The Netherlands; Durnin, 1987). In Guatemala, women living in an urban area gained more: 10.0 kg of weight, 6.2 kg of fat and 5.3 kg of fat-free mass during pregnancy (Villar *et al*, 1992). With the nutrition transition, this will soon be the case for many societies. Currently, there are no data on weight gain during pregnancy among groups of women in less affluent societies, among whom obesity is increasing.

Dietary intake and exercise

For many rural women, season is a proxy for changes in dietary intake, physical activity and illness experience (Roberts *et al*, 1982). These factors are not easily separable and data are not available on how they each might influence MNS during pregnancy. It is known, however, that net changes in body composition during pregnancy can be significantly affected by the season(s) during which pregnancy occurs. For example, during the season of food availability, Gambian women gained 3 kg of body fat, but during the season of food scarcity they lost 4.7 kg of fat during pregnancy (Lawrence *et al*, 1987). In this same community, weight gain during pregnancy has been reported as 5.5 kg in the better season and half this much in the worse season (Thomson *et al*, 1966). Both weight gain and changes in arm circumference during pregnancy are affected by season in Bangladesh (Chowdhury, 1987).

Prepregnant weight and BMI

In less affluent countries, the effect of prepregnancy weight and BMI on weight gain during pregnancy varies across studies. In West Java (Indonesia), Taiwan and Tanzania, heavier women have been observed to gain more weight during pregnancy (Achadi *et al*, 1995; Adair *et al*, 1983; Möller *et al*, 1991). In Kenya, Mexico and Papua New Guinea, the opposite has been observed, while no association was found in Egypt (Garner *et al*, 1994; Adair *et al*, 1983; Allen *et al*, 1994).

Smoking

Smoking rates remain substantially lower among women living in less affluent compared with affluent societies, although there is concern that rates may be rising, with current reported rates around 13–25% in Central and Latin America and the Caribbean, <10% in African coun-

tries and <5% in much of South Asia (WHO, 1997). Due to limitations in the quality and quantity of information from these regions, little is known about the impact that smoking is having on MNS during pregnancy in less affluent areas.

Age and parity

In many traditional societies, women are likely to achieve high parity. Remarkably little is known about how high parity might influence changes in MNS during pregnancy, although high parity is associated with both lower birth-weight and poorer subsequent infant growth (Prentice *et al*, 1987). In a study in West Java, Indonesia, researchers failed to find any effect of parity on pregnancy weight gain (Achadi *et al*, 1995). The same was true for both age and parity in a study conducted from prepregnancy until postpartum in Central Java, Indonesia (Winkvist *et al*, 2002).

In sum, weight retention after pregnancy is affected by maternal growth during pregnancy (more weight gain), low initial BMI (more weight gain in women in affluent societies; mixed effect in women in less affluent societies), smoking (less weight gain), as well as exercise, illness and low dietary intake (less weight gain). No effect of maternal age or parity has been found.

Changes in MNS during lactation in affluent societies

We have previously reviewed the effect of lactation on MNS (Winkvist & Rasmussen, 1999). Here, we give a brief summary and an update of the major conclusions from that review. Only modest weight loss occurs during lactation in affluent societies (Institute of Medicine, 1991) and some women may even gain weight (Manning-Dalton & Allen,

1983). Hence, other determinants of weight loss besides lactation may be of greater importance during this period (Schauberger *et al*, 1992; Janney *et al*, 1997; Butte & Hopkinson, 1998; Thorsdottir & Birgisdottir, 1998). Negative changes in body fat are generally reported, although with varying magnitude (Butte *et al*, 1984, 1985; Institute of Medicine, 1991; Dewey *et al*, 1993; Sadurskis *et al*, 1988; Forsum *et al*, 1989; Soltani & Fraser, 2000). Higher rates of weight loss have been reported among women who fully breastfeed their infants than among mothers who partially breastfeed their infants (Brewer *et al*, 1989; Dewey *et al*, 1993; Kramer *et al*, 1993; Öhlin & Rössner, 1990; Janney *et al*, 1997).

Dietary intake and exercise

Studies from the US, UK, New Zealand, Sweden and The Netherlands indicate that well-nourished lactating women consume more energy than NP/NL women (Institute of Medicine, 1991; Black *et al*, 1986; Goldberg *et al*, 1991; Todd & Parnell, 1994; Sadurskis *et al*, 1988; Van Raaij *et al*, 1991). In these studies, total intakes were below recommended levels, which may reflect underestimation in the dietary assessment and/or conscious efforts by lactating women to lose weight gained during pregnancy.

Reduced levels of physical activity during lactation have been reported in a few studies (Van Raaij *et al*, 1991; Goldberg *et al*, 1991), and a relationship between perceived reduction in physical activity during pregnancy and greater risk of long-term weight gain was found in one study (Harris *et al*, 1999). Other investigators have reported that vigorous physical activity in combination with increased dietary intake did not lead to further weight loss than that among sedentary lactating women (Lovelady *et al*, 1990; Dewey *et al*, 1994). However, dieting in combination with physical activity may lead to larger losses of weight and fat mass (Lovelady *et al*, 2000), whereas dieting alone may lead to losses of both fat mass and fat-free mass (McCrorry *et al*, 1999). The effect of illness during lactation on MNS in affluent societies has not been evaluated.

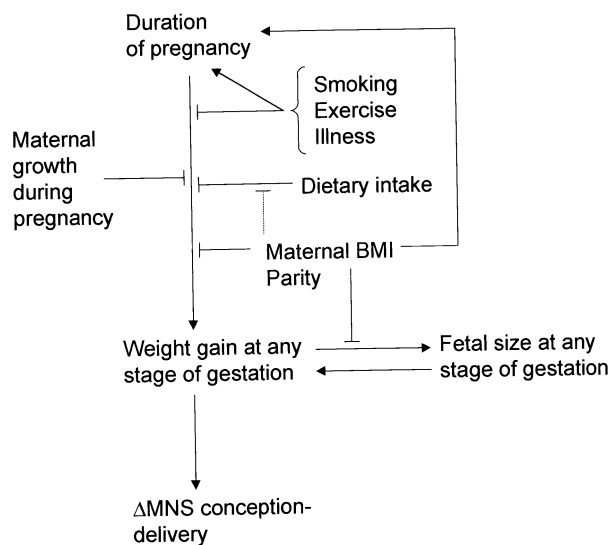


Figure 2 Factors affecting changes in maternal nutritional status (Δ MNS) during pregnancy (body mass index, BMI).

Age and parity

In one American study, an association between older age and slower rate of weight loss postpartum was reported (Janney *et al*, 1997). In contrast, some studies of very young mothers have suggested the reverse. Specifically, adolescent growing mothers may retain more weight, triceps and subscapular skinfolds thickness and arm fat area during the first 4–6 weeks as well as the first 6 months postpartum than do non-growing adolescent mothers or mature mothers, given similar dietary intakes (Scholl *et al*, 1993, 1994, Scholl & Hediger, 1995).

Maternal BMI

No associations were found between maternal BMI in early pregnancy and weight loss pattern during the first 6 months of lactation among British women (Soltani & Fraser, 2000). However, women who were obese in early pregnancy, compared with women who were of normal-weight or overweight, experienced different patterns of changes in skinfold thickness, waist-hip ratio and fat mass during the postpartum period and developed central obesity (Soltani & Fraser, 2000). A high proportion of women in affluent societies are overweight and obese. Obese women may be less successful in initiating as well as sustaining lactation than normal-weight women (Rutishauser & Carlin, 1992; Hilson *et al*, 1997; Donath & Amir, 2000).

Smoking

Results from studies in Germany (Schwartz-Bickenbach *et al*, 1987) and the US (Hopkinson *et al*, 1992) showed smoking mothers to wean their children significantly earlier than non-smoking mothers. Further, both milk volume and fat concentration were lower in milk from smoking mothers than non-smoking mothers (Hopkinson *et al*, 1992). These findings may explain the earlier weaning among smoking mothers together with reluctance to expose the baby to tobacco via breastmilk. However, no research is available to address the modifying effect of smoking on changes in MNS during lactation.

Changes in MNS during lactation in less affluent societies

During the first 3 months postpartum, reported mean changes in weight among lactating women in Asia, Africa and Latin America have ranged from -0.73 to $+0.70$ kg/month (Butte & Hopkinson, 1998). Substantial weight loss has been reported only in relation to severe food restriction (Prentice *et al*, 1981). Between 3 and 6 months postpartum, the range varied from -0.80 to $+0.45$ kg/month. Reported changes between 0 and 6 months postpartum in maternal skinfold thicknesses and estimated total body fat have been negative in most studies (Dorea, 1997). The few investigators that followed lactating women beyond 6 months postpartum found the following 12 month interval to be associated with weight loss; lactation beyond 1.5 y was associated with weight gain (Delgado *et al*, 1985; Adair & Popkin, 1992, Miller *et al*, 1994).

The effect of breastfeeding intensity on changes in MNS was evaluated in only one study, this one among women in the Philippines (Adair & Popkin, 1992). A complex pattern emerged, where both area of residence and period of breastfeeding affected weight change pattern.

Dietary intake, exercise and illness

Most results from studies conducted in less affluent societies have shown higher dietary intakes among lactating women

than among pregnant or NP/NL women (Prentice *et al*, 1981; Guillermo-Tuazon *et al*, 1992; Kusin *et al*, 1993; Martínez *et al*, 1994; Piers *et al*, 1995), although a few studies failed to do so (Schutz *et al*, 1980; Adair, 1992). Among Filipino women, higher energy intake during lactation was associated with higher maternal postpartum weight (Adair & Popkin, 1992).

Inconsistent results on levels of physical activity among lactating women have been reported, as compared with pregnant or NP/NL women. A few investigators have found no difference or lower levels of physical activity during lactation (Tuazon *et al*, 1987; Singh *et al*, 1989; Kusin *et al*, 1993; Panter-Brick, 1993; Butte *et al*, 1997), whereas others have found higher levels during lactation (Armar-Klemesu & Wheeler, 1989; Madhavapeddi & Narasinga Rao, 1992). Among Filipino women (Adair & Popkin, 1992), higher energy expenditure was associated with greater risk of weight loss between 2 and 24 months postpartum. Lactating women who had severe respiratory infections were non-significantly more likely than those without such illness to lose weight during this time.

Age and parity

In Gambia, researchers have found that high maternal parity is associated with lower concentrations of fat, nitrogen and immunoproteins as well as lower milk volume (Prentice, 1986). In the Philippines, high maternal age was associated with greater risk of weight loss 2–24 months postpartum; parity was also included in the model but had no effect on the likelihood of losing weight (Adair & Popkin, 1992). In Bangladesh, high maternal parity was associated with higher rates of postpartum weight loss; here maternal age was not included in the model because of high correlation with parity (Miller *et al*, 1994). Finally, in Indonesia no effect of parity on rate of postpartum weight loss was seen (Kusin *et al*, 1994).

Maternal BMI

MNS during earlier parts of the reproductive cycle appears to affect weight changes during lactation. Two distinct patterns of weight change during lactation, in relation to earlier MNS, have been reported in less affluent areas. In studies from Indonesia (Kusin *et al*, 1994), Bangladesh (Miller *et al*, 1994) and Taiwan (Adair *et al*, 1983) investigators have found an association between poor MNS at conception, higher weight gain during pregnancy (but insufficient to compensate for the poor MNS at conception) and slower rate of weight loss (or even weight gain) during lactation. Results from studies in Guatemala (Winkvist, 1992) and Pakistan (Winkvist *et al*, 1994) revealed associations between poor MNS after delivery and slower rates of weight loss or even weight gain during lactation. This pattern implies the existence of compensatory mechanisms, eg reduced BMR, diet-induced thermogenesis, or muscular efficiency (Schutz *et al*, 1980; Lawrence &

Whitehead, 1988; Guillermo-Tuazon *et al*, 1992; Madhava-peddi & Narasinga Rao, 1992; Piers *et al*, 1995; Butte *et al*, 1997; Spurr *et al*, 1998; Prentice & Prentice, 1990).

The second pattern, which contradicts the first, has been shown in Mexico and Kenya (Martínez *et al*, 1994). Here, an association between poor MNS at conception, again higher weight gain during pregnancy but thereafter higher rates of weight loss during lactation has been found. Results from studies in the Philippines (Adair & Popkin, 1992) and Mexico (Barbosa *et al*, 1997) showed an association between poor MNS at delivery and higher rates of weight loss during lactation.

Finally, poor MNS may also delay ovulation (Peng *et al*, 1998), thus extending the period until next pregnancy of potential repletion. Still, high lactation intensity may be more important than poor MNS in delaying ovulation (Kurz *et al*, 1993).

Smoking

As in affluent societies, maternal smoking in less affluent areas is associated with earlier weaning, lower milk volumes, and slower infant growth up to 3 months of age than among non-smokers (Horta *et al*, 1997; Vio *et al*, 1991; Salazar *et al*, 1998).

In sum, weight loss during lactation is affected by high intensity (more weight loss), reduced dietary intake and more exercise (more weight loss; however, commonly women increase dietary intake and reduce exercise), illness (more weight loss in women in less affluent societies), smoking (weaning may take place earlier, leading to less weight loss), and initial BMI (obese women in affluent societies develop central obesity; women of low initial BMI in less affluent societies gain more weight during pregnancy and either gain even further weight during lactation or lose the extra weight gained during pregnancy). No clear pattern with maternal age has been found.

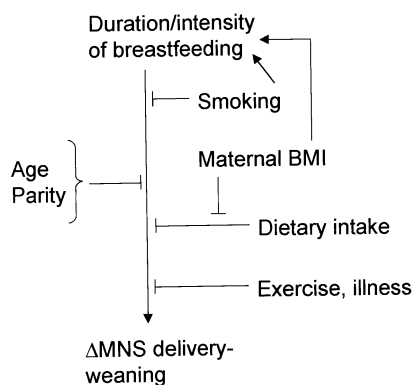


Figure 3 Factors affecting changes in maternal nutritional status (Δ MNS) during lactation (body mass index, BMI).

Changes in MNS during period of non-pregnancy/non-lactation (NP/NL) in affluent societies

Results from both cross-sectional and longitudinal studies indicate that women gain weight until around 70 y of age, after which they start losing weight. It has been reported that between the ages of 18 and 50 y, women gain 0.35 kg/y when they are not pregnant (Brown *et al*, 1992). With respect to women of reproductive age, changes in nutritional status during NP/NL may differ among women who have never been pregnant, women who have delivered a child but chose not to breastfeed, and women who have recently weaned their child. This is because these groups of women may differ systematically. For example, women who are very lean or very obese may be those who are less likely to conceive and who remain NP/NL (Zaadstra *et al*, 1993).

American women who had never been pregnant were followed for 1 y (Motil *et al*, 1998) and 5 y (Smith *et al*, 1994). Overall increases in body weight in the former study corresponded to 0.77 kg/y (mostly white women) and in the latter study 0.54 kg/y for white women and 1.12 kg/y for black women. In The Netherlands, women who were currently not pregnant or lactating but not necessarily nulliparous were studied for almost 2 y; mean increase in BMI was 0.15 kg/m² (Rookus *et al*, 1987). Finally, among nulliparous and parous white American women followed over a 10 y period, those who did not become pregnant during the observation period gained on average 3.8 kg (Williamson *et al*, 1994). Among women who had delivered a child but chose not to breastfeed, body weight loss over a 1 y period equalled 1.9 kg (Motil *et al*, 1998). In short, true weight stability over time is rare among adults in affluent societies and, in any given year, about 20% have changed 5 kg or more (Lissner, 1996). These 'normal' weight changes must be considered when assessing the prevalence of weight changes attributable to reproductive events.

Dietary intake and exercise

Among American women of all parities followed for 3 y (9% became pregnant during this period), weight gain corresponded to 0.68 kg/y (Klesges *et al*, 1992). Higher work and leisure activity at baseline was associated with lower weight gain. Increased energy intake and decreased work, compared to baseline, were associated with higher weight gains.

Women's BMI

In the study above of American women (Klesges *et al*, 1992), women with higher baseline body weights experienced less weight gain over the follow-up period. Other studies show that obese populations have experienced accelerated rates of weight gain during adulthood (Lissner, 1996).

Age and parity

No studies evaluate modifying effects of age/parity on amount of weight change during the NP/NL period. However, cross-sectional studies of age/parity and women's weight have most commonly found positive associations (Brown *et al*, 1992; Farahati *et al*, 1993; Rush *et al*, 1996; Harris *et al*, 1997). Still, these associations are modified by sociodemographic and behavioural factors: the amount of weight associated with parity is higher for black women than white women, higher for nonsmokers than smokers, and higher in those with low levels of recreational exercise (Wolfe *et al*, 1997). Some investigators have reported parity to be associated with centralization of body fat distribution, independent of relative weight *per se* (Björkelund *et al*, 1996).

Smoking

Smoking mothers are more likely to begin the NP/NL interval earlier than non-smokers because they are less likely to breastfeed their infants. If they do choose to breastfeed, the duration of lactation is shorter among smoking than among non-smoking mothers (see lactation section; Hopkinson *et al*, 1992), which leads to an earlier return of ovulation among smokers than non-smokers. Smoking women gain less weight over time than non-smoking women (Klesges *et al*, 1992) and their pre-gravid weight may be lower than that of non-smoking women (Albuquerque *et al*, 2001). This may reflect the higher (about 10%) basal metabolic rate among smokers (Rössner, 1986). Dietary intake among smoking women compares unfavourably to diets of non-smokers (Dallongeville *et al*, 1998). Once women quit smoking, they gain on average 3.8 kg (Williamson *et al*, 1991).

Hormonal influences (contraceptives)

Most recent studies have failed to find any effect of oral contraceptives on weight change in women (Pelkman *et al*, 2001).

Changes in MNS during period of non-pregnancy/non-lactation (NP/NL) in less affluent societies

In less affluent societies, no studies of changes in nutritional status among never-pregnant women have been reported. Five longitudinal studies of nutritional status have been carried out among women of all parities, where pregnant women have been excluded (lactating women may have been included). Follow-up period was 1y for all studies except the one from Bangladesh, in which women were followed for 2y. Indonesian women exhibited a mean increase of 0.7 kg/y, and this may reflect a society experiencing the nutritional transition (Winkvist *et al*, 2000). Results from the other four studies showed pronounced seasonal weight fluctuations. Nomadic Nigerian women experienced a weight difference of 2.7 kg between the best and the worst

season (Loutan & Lamotte, 1984) and among Ethiopian women the same difference was 1.3 kg (Branca *et al*, 1993). Further, Bangladeshi women exhibited fluctuations of 0.5–1.5 kg during 6-month periods (Huffman *et al*, 1985) and Nepali women exhibited increases as well as decreases of over 1 kg between seasons (Panter-Brick, 1993).

Three cross-sectional studies have evaluated effect on MNS of time since delivery among non-pregnant women; these women may have still been breastfeeding during part of the observation period. Among women in Lesotho, a negative association was found between time since delivery and BMI for the period until 12 months postpartum; thereafter a positive association was found (Miller & Huss-Ashmore, 1989). Predicted BMI was thus highest for women 12–17 months postpartum. Using similar analytical techniques with data from Bangladesh, Miller and colleagues described negative associations between time since delivery and weight until 16 months postpartum and thereafter a positive association (Miller *et al*, 1994). However, among Papua New Guinean women, the sum of four skinfold thickness measurements decreased with time since last delivery also beyond 12 months postpartum (Tracer, 1991).

Dietary intake, exercise and illness

The effects of season described by the four longitudinal studies above likely capture the negative effects of increased physical activity and decreased dietary intake on women's weight changes. In a cross-sectional, four-country study, high morbidity was found to predispose adult women to low BMI in Pakistan and Kenya, but no such relationships were found in the Philippines or Ghana (Garcia & Kennedy, 1994).

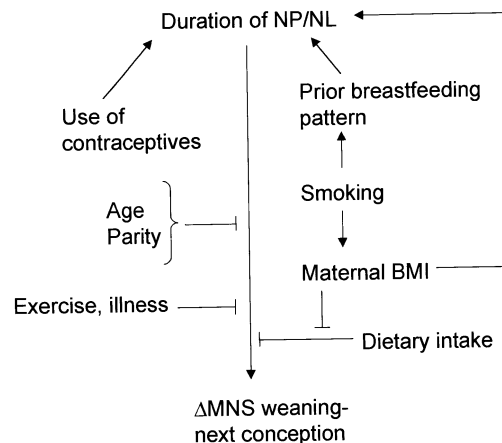


Figure 4 Factors affecting changes in maternal nutritional status (Δ MNS) during period of non-pregnancy/non-lactation (NP/NL) (body mass index, BMI).

Women's BMI

As described earlier, poor nutritional status may delay ovulation (Peng *et al*, 1998) and so extend the NP/NL pe rioid.

Age and parity

In most societies, age and parity are intimately related and their independent effects on weight changes are difficult to characterize even when sophisticated statistical techniques are applied. The effects of age and parity on weight changes are described in two longitudinal studies of non-pregnant women. Among Bangladeshi women, higher age and higher parity were both associated with lower weight and BMI, but patterns of weight and BMI changes over time were the same for all age and parity strata (Huffman *et al*, 1985). Among Indonesian women, 1 y weight increases were slightly lower among older women, but neither age nor parity was a significant risk factor for developing either obesity or chronic energy deficiency (Winkvist *et al*, 2000).

Associations between age and/or parity and weight among non-pregnant women are reported in a large number of cross-sectional studies. A negative association between parity/age and maternal weight was reported in a few of these studies (Venkachatalam, 1962; Chowdhury, 1987; Tracer, 1991; Garner *et al*, 1994; Ahmed *et al*, 1998). In contrast, a positive association (Reinhardt, 1980) or no association at all (Costello, 1986; Omran & Standley 1976, 1981; Prentice *et al*, 1981; Srivastava *et al*, 1998; Hindin, 2000) was observed in other studies.

In sum, weight change during periods of NP/NL is affected by reduced dietary intake and increased exercise (weight loss), higher BMI (less weight gain among women in affluent societies), higher age or parity (weight gain among women in affluent societies; mixed effect among women in less affluent societies) and smoking (less weight gain). No effect has been found for oral contraceptives.

Changes in MNS during overlap between lactation and next pregnancy in affluent societies

Breastfeeding concurrent with pregnancy occurs also in affluent societies (Garza, 1985; Moscone & Moore, 1993). A non-pregnant lactating woman may mobilize body fat equivalent to 840 kJ/day; whether this also occurs among women who are experiencing overlap is unknown. However, the quantity of milk produced decreases after the first few months of pregnancy, perhaps as a result of the increased production of progesterone during pregnancy in women experiencing overlap (Garza, 1985). No research from affluent societies is available that address the impact of overlap on MNS.

Changes in MNS during overlap between lactation and next pregnancy in less affluent societies

A new pregnancy is one of the main reasons for weaning in many less affluent societies (Böhler & Bergström, 1996).

Nonetheless, high prevalence of overlap between lactation and pregnancy has been reported from India, Guatemala, Indonesia, Senegal, Bangladesh, the Philippines, Bhutan and Peru (Ramachandran, 1987; Merchant *et al*, 1991; Böhler & Ingstad, 1996; Marquis & Penny, 2000). In the Indian study, one-third of pregnancies in a low-income population occurred among lactating women (Ramachandran, 1987). In the Guatemalan study of pregnant and lactating women, over 50% of the pregnancies occurred concurrent with lactation (Merchant *et al*, 1991). Among those with overlap, 41.4% continued breastfeeding beyond the first trimester and 3.2% continued in the third trimester. Finally, in a study of growth of 113 young breastfed children in Bhutan, only one was weaned without a new pregnancy; median time of overlap was 5 months (Böhler & Bergström, 1996).

In the Indian study, body weight was lower among women who experienced overlap, especially if conception occurred during the first 6 months of lactation (Ramachandran, 1987). In the Guatemalan study, overlap was associated with a higher intake of a nutritional supplement offered, but no significant effect on maternal fat stores was detected (Merchant *et al*, 1990a, b). Breastfeeding while being pregnant is associated with different feeding practices than breastfeeding only (eg tending to provide other liquids more frequently), and with a higher proportion of infants receiving low amounts of breast milk (Marquis & Penny, 2000). The composition of colostrum may also differ (eg lower lactoferrin and higher lysozyme concentration in milk from overlapping mothers; Marquis *et al*, 2002).

In sum, no studies exist from affluent societies on weight changes during periods of overlap. In less affluent societies, overlap tends to be associated with weight loss but no studies address factors modifying this relationship.

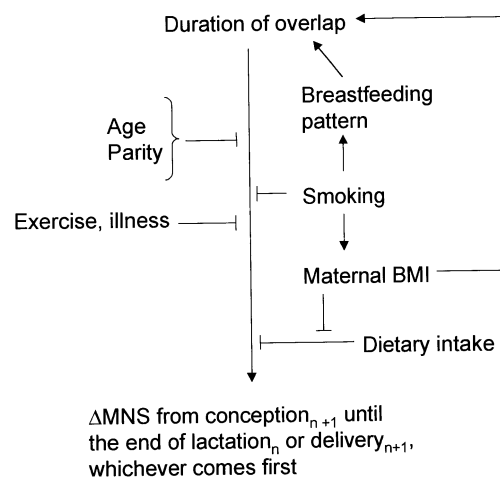


Figure 5 Factors affecting changes in maternal nutritional status (Δ MNS) during period of overlap between pregnancy and next lactation (body mass index, BMI).

Summary over the reproductive cycle

In conducting this review, the dearth of longitudinal data with which to examine our conceptual framework became evident, particularly for the NP/NL interval and the overlap between lactation and next pregnancy. Pregnancy is the best studied component part of the reproductive cycle and recent research has provided more information about lactation than was available earlier. Few comparative studies are available, so the range of initial MNS in any one study is limited. This makes it difficult to know if reported differences between populations result from differences in study design and methods or from differences in biological or other factors. The lack of suitable comparison groups to women experiencing pregnancy or lactation further complicated this review.

In summary, we found that women in affluent societies retain some weight with each pregnancy beyond that of non-pregnant women. In comparison, women in less affluent societies retain less weight with each pregnancy. Growing adolescent mothers retain relatively more weight. In contrast, smoking mothers retain relatively less weight. Dietary intake and exercise influence weight gain, but parity and prepregnant BMI have no or mixed effects.

During lactation, women in both affluent and less affluent societies experience only modest weight loss—the former group may even experience weight gain. This gain is closely associated with a tendency of higher dietary intake and less physical exercise, compared to before pregnancy. In affluent societies high prepregnant BMI is associated with shorter breastfeeding period. In less affluent societies, low prepregnant BMI is either associated with both high weight gain during pregnancy and low rate of weight loss during lactation, or with high weight gain during pregnancy and high rate of weight loss during lactation. Smoking is associated with shorter breastfeeding period. Age and parity have mixed effects on change in MNS during lactation.

In affluent societies, the weight of never-pregnant women increases over time until around 70 y, whereas the weight of NP/NL women who have recently weaned their child may decrease as the result of conscious efforts. In less affluent societies, weight is likely to fluctuate and poor dietary intake and high physical activity (determined by season) have a major impact. In affluent societies, high BMI is associated with less weight gain, whereas higher age and parity are associated with more weight gain. In less affluent societies, low BMI is associated with longer NP/NL period. No clear association between age and parity and weight change is seen.

Finally, no data exist from affluent societies on weight changes during overlap of lactation with next pregnancy, whereas in less affluent societies lower weights have been observed. However, the energetic demands of overlap may be compensated for by increased dietary intake and shorter periods of exclusive breastfeeding.

Even though the ultimate interest is in the overall effect of a full reproductive cycle, the form of the available informa-

tion makes it difficult to link data from one part of the reproductive cycle to another. This is unfortunate, because some factors may influence MNS in several component parts. One example is smoking, which leads to preterm birth and may be associated with difficulties in establishing lactation. Thus, we can at best speculate how the different parts of the reproductive cycle exert their joint effects when the full cycle is evaluated.

Firstly, behavioural mechanisms may come into play, and these are likely to differ in different parts of the world. For instance, the weight of affluent women who have recently weaned their child may decrease as the result of conscious efforts, and this motivational factor may vary across groups of different socio-economic status. In less affluent societies, access to contraceptives may be limited, leading to shorter NP/NL and less possibility to replenish the body stores.

Secondly, biological mechanisms may come into play. For instance, maternal obesity, an increasingly prevalent condition in both affluent and transitional regions, may itself be a modifier of lactation initiation, thereby creating a predisposition for maintenance of pregnancy weight gain among already obese women.

In addition, in less affluent societies initial MNS may influence the nutritional response of the mother to reproduction. Poor initial MNS may stimulate adaptive mechanisms (eg reduced basal metabolic rate, reduced diet-induced thermogenesis, increased muscular efficiency), leading to lower total cost of the pregnancy and lactation. Also, there is some suggestion that initial MNS may influence the partitioning of resources between the mother and her foetus or infant and, thus, the degree of compensation in MNS that may occur. Thus, women with the lowest initial MNS may experience a positive change in MNS during a reproductive cycle concurrent with negative effects on her newborn.

In conclusion, available literature suggest that women in the middle of the distribution of initial MNS experience minimal changes in nutritional status as a result of reproduction unless their weight gain during pregnancy is excessive and they also fail to lose this excess weight before their next conception. For women at the extremes of the distribution of initial MNS, however, the effects of reproduction may be more dramatic. For those at the low end, reproduction may produce frank maternal depletion. For those at the very lowest end, reproduction may stimulate adaptive mechanisms that in the short term benefit MNS but in the long term may have negative effects on maternal life expectancy and life quality. Finally, for those at the high end, reproduction may in some cases make a high initial BMI higher still, perhaps leading to obesity among those who are genetically susceptible. As a result, it is particularly challenging to provide clear and consistent recommendations to women about weight changes during the reproductive cycle in societies in transition, including women at both extremes of the continuum of initial MNS. The recommendations will depend not only on the biolo-

gical relationships that this paper discusses, but also on the stage of development of the society and the social context in which the woman lives.

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