SCIENTIFIC SECTION

Review Articles

Maternal nutrition in pregnancy. Part I: a review

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Maternal undernutrition may result in a greater deprivation of the fetus than has previously been believed. The infant not only may be "light for dates" but also has an increased risk of perinatal disability or death secondary to gross neurologic and developmental abnormalities. This article reviews current knowledge of the energy, protein, iron, vitamin, sodium and calcium requirements in pregnancy, with special reference to the management of the underweight and overweight pregnant woman.

La sous-nutrition maternelle peut résulter en une carence plus grande pour le foetus qu'il n'avait été préalablement anticipé. Non seulement le bébé peut être "léger pour son âge" mais aussi présente-t-il un risque accru d'infirmité ou de mort périnatales dues à de graves anomalies neurologiques ou de développement. Cet article passe en revue les connaissances actuelles sur les besoins en énergie, protéines, fer, vitamines, sodium et calcium durant la grossesse, et une attention particulière est accordée à la conduite à prendre chez la femme maigre ou obèse.

Maternal nutrition has been recognized for its importance to the course and outcome of pregnancy.[1] However, despite the considerable work reported in the literature, many obstetricians, especially in North America and western Europe, still perceive nutrition counselling as a secondary aspect of prenatal care. Although there is a high standard of living in these areas, a small proportion of the population has, for a variety of reasons, an inadequate dietary intake during pregnancy. It is well established that low weight before pregnancy and inadequate weight gain during pregnancy are significantly correlated with low birthweight, regardless of the mother's height.[2] Young[3] has suggested that nutritional factors may account for 60% of the observed variation in birthweight. Furthermore, inadequate weight gain during pregnancy may be the only feature apparently related to growth retardation in the infant. The preliminary results of a study in New York City suggest that suboptimal fetal growth occurs when the mother's weight falls below 100% of the ideal for her.[4]

Recent data from studies with animals challenge the traditional view that the fetus has "parasitic" qualities that allow it to thrive in the face of moderate maternal malnutrition. The developing fetus may not be a successful parasite during nutritional deprivation and may be more severely affected than its mother.[4-6]

In this article, the first of two papers, we will discuss the consequences of maternal undernourishment in pregnancy, and in part II we will review special situations in which maternal gastrointestinal disease and previous bowel surgery may compromise the mother's ability to adequately nourish herself and her fetus.

Pattern of normal weight gain

Maternal weight gain is accounted for by the fetus, the placenta and the woman's compensatory changes for pregnancy and subsequent lactation. The issue of optimum weight gain is controversial. The committee on nutrition of the American College of Obstetricians and Gynecologists recommends 10 to 12 kg; the incidence of obstetric complications seems lowest and the outcome best at these values. However, the pattern of weight gain may be more important than the absolute amount gained.[7]

In the first trimester the weight gained is usually minimal, about 1 kg. However, after the 9th week there seems to be a linear increase of 0.3 to 0.4 kg per week until term. In the second trimester the weight

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gain occurs mainly in the maternal compartment (with expansion of the blood volume, uterine and breast hypertrophy, and accumulation of adipose tissue), and in the third trimester the gain is primarily in the products of conception (the fetus, placenta and amniotic fluid). At term the maternal compartment is responsible for approximately 6 kg and the fetal compartment 5 kg of the 11-kg average total weight gain.

Inadequate weight gain during pregnancy is usually defined as a gain of 1 kg or less per month in the second and third trimesters. It is associated with a lower birthweight and a higher risk of maternal complications. Therefore, patients with an inadequate weight gain must receive careful dietary counselling to restore a normal pattern of weight gain.

Excessive weight gain is considered to be a gain of 3 kg or more per month in the second and third trimesters of pregnancy. It is important to differentiate weight gain caused by edema in the maternal and fetal compartments. Excessive weight gain is not associated with pre-eclampsia, but it may contribute to postpartum maternal obesity. Dependent edema occuring during pregnancy is generally physiologic. It may be due to the influence of estrogen on the mucopolysaccharide of the ground substance, a decrease in the plasma oncotic pressure caused by hypoalbuminemia, or a change in the physiologic mechanisms that promote sodium retention.[7] Ankle edema may also be due to obstruction of the pelvic veins by the enlarged uterus. However, nondependent edema may presage pre-eclampsia.

Special nutritional considerations

The underweight patient

An underweight woman is defined by the Society of Obstetricians and Gynaecologists of Canada as one who becomes pregnant at a weight of less than 47 kg, or 20% or more below the standard for her height and age.[1] A low weight before pregnancy ranks closely behind subnormal cumulative weight gain during pregnancy as a determinant of low birthweight and contributes to a disproportionate amount of neonatal mortality. As well, pregnant women of low weight are at an increased risk of pre-eclampsia, eclampsia, antepartum hemorrhage and premature labour.[8]

The obese patient

An obese patient is one who becomes pregnant at a weight 20% or more above the standard for her height and age.[1] The obstetric complications arise mainly from associated diseases, such as hypertension, diabetes mellitus and thromboembolic phenomena, rather than from the obesity itself.[9] Weight reduction or marked restriction of weight gain during pregnancy is hazardous, as the necessary nutrients may not reach the fetus in quantities sufficient for its development. Dieting can cause starvation ketosis, which is harmful to the fetus. Energy and protein intake should be adequate to support a normal pattern of weight gain. Therefore, a weight-reducing regimen should only be instituted post partum in nonlactating women.

Some consequences of maternal malnutrition

Experiments with animals have shown that intrapartum nutritional deprivation can result in gross neurologic and developmental problems and increased morbidity and mortality in the infant. Studies with rats have shown a substantial decrease in body weight, placental weight, cerebral weight (protein and deoxyribonucleic acid [DNA]) and the number of brain cells.[6,7,10] As well, the expansion of plasma volume and the rate of transfer of nutrients across the placenta are decreased.[4] From birth, these nutritionally deprived animals show abnormalities in nitrogen and carbohydrate metabolism even when they are nursed by adequately nourished foster mothers.[11] The offspring of malnourished mothers have shown impaired learning ability and abnormal responses to various stimuli. The more prolonged and severe the malnutrition, the more profound were the consequences. Despite adequate feeding of the offspring, two further breedings were required before litters with a normal pattern of growth and development were produced.[11] This finding may be explained by Zeman and colleagues' observation in rats that maternal protein malnutrition resulted in a reduction in neonatal gastrointestinal function, with decreased postnatal lactase and alkaline phosphatase activities in the small intestine.[12] In another study growth-retarded offspring showed decreased intestinal absorption of amino acids, sugars and fats.[13] These factors may influence the ability of a newborn to regain a normal pattern of mental and physical growth and development.

Indirect data indicate that the findings in animals are similar to those in humans. However, the consequences of maternal malnutrition are less well defined in humans because there are no controlled studies described in the literature. It is difficult to separate the effects of nutritional deprivation from the interrelated effects of poverty, lack of education, social deprivation, and chronic infections and illnesses.

In studies on humans weight gain during pregnancy has been used as an index of adequate maternal nutrition. This weight gain ranks second only to the duration of pregnancy as a determinant of birthweight.[14] Birthweight, in turn, has been correlated inversely with perinatal mortality and directly with neurologic development of the neonate.[14] The often-cited studies of pregnancy during the famines in Leningrad[15] and Rotterdam[16] during World War II suggest that there was a downward trend in birthweight associated with a reduction in daily nutritional intake, and that the most substantial decrease in mean birthweight was related to poor nutrition late in pregnancy. A study in Britain in 1968 showed that the 7% of infants who weighed 2500 g or less at birth accounted for 65% of the perinatal deaths.[17] Compared with white infants, black infants in New York City weigh less and have nearly twice the perinatal mortality; however, if the black babies had the same weight distribution as the white

babies their perinatal mortality would be reduced to the same level.[14]

It seems that an undernourished pregnant woman is able to compartmentalize available nutrients and reduce their rate of transfer to the fetus.[5] At the cellular level humans respond to maternal malnutrition in much the same way as lower animals. Prenatal growth is predominantly proliferative, with an increase in the number of cells (i.e., hyperplasia). Examination of malnourished fetuses has shown a smaller number of cells, lower organ weights and reduced content of total ribonucleic acid, DNA, protein, cholesterol and phospholipid in the brain.[6,7,10] The differences are most marked between malnourished and normal infants when the deprivation occurs after 33 weeks' gestation.[18] Malnourished infants also show a lag in psychomotor development.[19,20]

Inadequate nutritional intake causes maternal metabolism of fat for energy and associated ketonemia. Pregnant women seem to be particularly susceptible to ketoacidosis when fasting;[21] in fact, ketonuria may develop after only 6 hours of fasting. At 4 years of age children of diabetic women in one study had lower intelligence quotients (IQs) if their mothers had had ketonuria.[22] To what extent this is true in children of nondiabetic women has yet to be determined. Excessive amounts of acetone appear to be neurotoxic to the fetus;[22] however, this problem can be prevented by adequate energy intake.

Poor nutrition, even in the absence of gross malnutrition, is harmful to not only the fetus but also the mother. Good maternal nutrition is associated with a lower risk of pre-eclampsia and fewer complications during labour and delivery.[6]

Requirements during pregnancy

Energy and protein

Pregnant women require energy for increased maternal metabolism and growth, and for growth of the fetal–placental unit. The total energy requirement for the usual pregnancy is approximately 314 000 kJ (75 000 Cal);[18] thus, an additional 1000 to 1250 kJ (250 to 300 Cal) per day is needed. However, these values do not take into account the additional energy requirements of maternal growth in the teenaged mother or the prepregnant malnourished woman. The energy requirements are not evenly distributed throughout gestation:[7] they are minimal in the first trimester but rise in the second and third trimesters. The Food and Agriculture Organization/World Health Organization recommends an additional 630 kJ (150 Cal) per day during the first trimester and 1500 kJ (350 Cal) per day during the second and third trimesters.

Approximately 1 kg of protein accumulates during pregnancy, as estimated from the nitrogen content of the fetal and maternal compartments.[23] Therefore, an additional 10 g of protein per day may have to be ingested to provide for the gain. If the accumulation is estimated by nitrogen balance studies the amount of protein needed to keep a patient in nitrogen equilibrium is two to three times greater. This may indicate nitrogen sequestration during pregnancy, possibly in the mother's gastrointestinal tract and liver.[6] Because of this discrepancy and the uncertainty about which value is correct, the higher values are used. Thus, an additional 30 g of protein per day during pregnancy is recommended. For pregnant teenagers the recommended amount is higher because of their continuing growth.

The serum protein levels change during pregnancy. The total serum protein and albumin concentrations decrease during the first trimester. The globulin level, especially the α and β fractions, rises, although the γ fraction remains the same. In the second trimester the decrease in the serum protein and albumin levels is less rapid, reaching 70% of the levels before pregnancy. Late in the puerperium these levels may become the same as they were before pregnancy.[6] The cause of these changes is not known. However, they may be related to endocrine factors, as similar changes are seen in women taking oral contraceptives.[24] Diet is probably not significant because the changes occur despite a diet enriched in protein.[7] However, the decrease in the serum protein concentrations may be even greater if the mother's diet is low in protein.

The protein in the amniotic fluid is contributed by both the mother and the fetus, though mostly by the mother.[6] The concentration of protein in the amniotic fluid declines progressively during pregnancy. The fetus is capable of swallowing and concentrating proteins in amniotic fluid in its gastrointestinal tract early in pregnancy. The proteins are broken down into amino acids and absorbed for storage in the fetus. A low protein level in the amniotic fluid is associated with a higher birthweight.[6] Studies of the patterns of amino acids in the cord blood and plasma of low-birthweight infants have shown low concentrations of the nonessential amino acids glutamine, alanine, glycine and ornithine and of the essential amino acid histidine.[25] In contrast, high tyrosine levels were present, and the levels correlated inversely with birthweight and gestational age.[25]

The implications of these findings are unclear. The results of an uncontrolled study in mildly to moderately malnourished pregnant women in Guatemala suggested that energy supplementation with carbohydrate alone is as effective as that with carbohydrate and protein in reducing the incidence of low birthweight and perinatal mortality.[20]

Iron

The fetus is able to extract iron from its mother, even if the mother's daily supply of iron is inadequate, because placental transfer favours the fetus. The fetus of an anemic woman is born with a normal hemoglobin level, although its supply of iron may be low and may therefore cause anemia later in infancy. If the mother's hemoglobin concentration is maintained at 6 g/dl or greater there is no increase in fetal morbidity.[26] However, lower hemoglobin concentrations are associated with prematurity and stillbirth.[27]

It can be difficult to diagnose latent iron deficiency anemia that is superimposed on the physiologic anemia

of pregnancy, because the mother's hemoglobin concentration is a poor index of iron values. Some authors have suggested that the most practical determinant of true iron values, and thus anemia, in pregnancy is the transferrin saturation,[10] while others prefer to examine the peripheral blood smear and to demonstrate the absence of iron in the bone marrow.[26]

Each pregnancy requires approximately 1 g of elemental iron to meet the requirements of augmented erythropoiesis, sequestration by the fetus and placenta, and blood loss during delivery. In women who are not pregnant, only 10% of ingested iron is absorbed. Although iron absorption is increased during pregnancy the increase is not sufficient to provide the amount required, even in the presence of the estimated 300 mg of iron normally stored in the body. It has therefore been recommended that the 30 to 60 mg/d of dietary elemental iron be supplemented by 300 to 600 mg/d of ferrous sulfate (20% to 30% of which is elemental iron).[7] With such supplementation hemoglobin levels below 11 g/dl are uncommon.[7] However, some authors still argue that iron supplementation is unnecessary and that its effect is pharmacologic rather than physiologic.

Vitamins

Folate deficiency is the most common vitamin deficiency in pregnancy.[26] The requirement for folic acid is markedly increased in the pregnant woman because of augmented erythropoiesis. Moreover, folic acid is required by the developing fetal and placental tissues. As well, more folate is excreted in the urine during pregnancy. The altered hormonal state may impair absorption and induce the synthesis of a protein in leukocytes and the serum that binds folate, preventing it from being used. Similar effects have been seen in some patients taking oral contraceptives.[24]

The folate levels in the erythrocytes and the serum decrease at around 16 to 20 weeks of gestation; 25% of patients may have a serum folate level of less than 3 mg/ml. However, full-blown megaloblastic anemia late in pregnancy seldom occurs in such patients. Megaloblastic anemia is best recognized by the characteristic changes in the peripheral blood, bone marrow and serum folate levels. Neonates of mothers with megaloblastic anemia typically have normal hemoglobin levels.[7] The significance of folate deficiency in pregnancy is not clear. Some investigators have found the deficiency to be associated with abruptio placentae, spontaneous abortion, fetal malformation and pre-eclampsia,[10,28] but others have failed to find a relationship between folate deficiency and these complications.[7,29] Routine supplementation of the diet with folate is a contentious issue, but folate certainly should be given to patients who are deficient in folate before they become pregnant, those with multiple pregnancies, malabsorption syndromes or chronic hemolytic anemia and those taking anticonvulsant drugs such as diphenylhydantoin.[26] In these instances the daily folate supplement should be 200 to 400 μg.

In the differential diagnosis of megaloblastic anemia vitamin B_{12} deficiency must be considered, although it is not common during pregnancy. The normal fetus requires only 50 μg of vitamin B_{12}, not an excessive demand on a normal maternal store of 3000 μg.[26] However, mothers who have been following a strict vegetarian diet may have a severe vitamin B_{12} deficiency, which will be aggravated by breast-feeding. Furthermore, the severe hematologic and neurologic manifestations of vitamin B_{12} deficiency may develop in the fetus. Therefore, vegetarians should supplement their diet with vitamin B_{12} during pregnancy and lactation.[30]

The blood level of vitamin B_6 (pyridoxine) decreases during pregnancy. Laboratory findings suggest that pregnant women become deficient in this vitamin, yet there are no well defined clinical studies showing any adverse effects of the deficiency. The recommended daily allowance of vitamin B_6 for an adult is 2 mg, with an additional 0.6 mg during pregnancy; however, this amount is insufficient to correct any biochemical abnormalities.[7]

In pregnant women the blood levels of other water-soluble vitamins are generally lower than in nonpregnant women. However, the clinical significance of this observation is controversial: whether this represents a true deficiency or is physiologic has not been determined.

The fat-soluble vitamins (A, D, E and K) cross the placenta less readily than the water-soluble vitamins and accumulate in the fetus at lower concentrations than in the maternal blood. The recommended daily allowance of vitamin A during pregnancy is 5000 IU, 25% more than for nonpregnant women. However, an excess of vitamin A can be teratogenic; congenital obstructive lesions in the urinary tract have been associated with hypervitaminosis A.[4,7]

Vitamin D is important in calcium metabolism and in the regulation of mineralization of the fetal skeleton. Deficiencies have been associated with congenital rickets and neonatal hypocalcemia, yet there does not seem to be an increased requirement for vitamin D in a healthy pregnant woman. Moreover, hypervitaminosis D may result in severe infantile hypercalcemia, with craniofacial abnormalities and supravalvular aortic and pulmonic stenosis.[10] The recommended daily allowance of vitamin D is 400 IU, the amount contained in approximately 1 litre of milk.

Maternal vitamin E deficiency has been associated with hemoglobinopathies in the newborn and vitamin K deficiency with hypoprothrombinemia, but it is not known how these deficiencies affect the development of the fetus.[10]

Sodium

Sodium is a contentious topic in obstetrics. Most obstetricians believe that pregnancy is a salt-wasting state that has effects ranging from benign to the hypovolemia and vasospasm characteristic of pregnancy-induced hypertension. With an average weight gain during pregnancy of 11 kg, 70% accounted for by water, approximately 1000 mmol of sodium is required to maintain isotonicity. At the same time, the sodium loss increases during pregnancy. The glomerular filtration rate rises by 50%, with a filtered sodium

load of 5000 to 10 000 mmol/d.[31] The sodium loss is augmented by the natriuretic effect of progesterone. The sodium depletion can be compensated for by the increased activity of the renin–angiotensin–aldosterone system. The renin activity rises, possibly because of the sodium loss and the decreased blood pressure. The production of renin substrate is also increased, owing to estrogen stimulation of the hepatic synthesis of angiotensin I (a decapeptide). In turn, large quantities of angiotensin II (the octapeptide formed from the decapeptide) are produced that stimulate aldosterone release from the adrenal cortex, which promotes tubular reabsorption of sodium and maintains maternal homeostasis. Angiotensin II can also stimulate arteriolar receptors and increase the blood pressure in nonpregnant women, but these actions are negated in pregnancy, possibly by the production of prostaglandin A from the uterus and kidney.[32]

The results of clinical studies conflict. While excessive sodium intake by patients with toxemia is frequently associated with a worsening of the disease, improvement has been noted in some patients with sodium administration. In view of this uncertainty the sodium intake should be neither restricted nor increased; the physiologic compensatory mechanisms alone can maintain homeostasis.[31] Sodium restriction does not appear to play an important role in the prevention of pre-eclampsia.[7] The use of thiazides and other diuretics to promote sodium excretion clearly is not necessary in a normal pregnancy and may result in electrolyte imbalance and volume depletion in the mother. Also, diuretics have been associated with abnormalities in some aspects of placental function because of lowered uterine blood flow. Other side effects include hyperglycemia, hyperuricemia and acute pancreatitis.[31]

Calcium

During pregnancy approximately 30 g (750 mmol) of calcium is required;[33] most of this is used for mineralization of the skeleton of the fetus in the third trimester (200 to 300 mg a day). Adequate calcium intake during the third trimester is particularly important, but equally important is adequate storage of calcium in the mother's skeleton early in the pregnancy. The serum calcium level in the mother decreases as the albumin content decreases, while the ionized calcium level is maintained by increased secretion of parathyroid hormone. The recommended daily allowance of calcium is 1200 mg, the amount contained in approximately 1 litre of milk. For patients who have lactase deficiency, calcium lactate or gluconate is suggested.

Trace elements

Deficiencies of trace elements in pregnant animals have been well documented as causing deleterious effects, but their clinical significance in humans is not well known.[8,10] In the human fetus zinc deficiency has been associated with short stature, marked hypogonadism, rough skin, hepatosplenomegaly and iron deficiency anemia.[6,10]

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