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Physiology of Pregnancy and Lactation

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The changes that occur in a woman's body during pregnancy may be compared to a revolution. The fetus imposes unique demands on maternal physiology, which undergoes profound changes during pregnancy. A considerable number of adjustments take place in most of the maternal organ systems. Such changes are needed to promote fetal growth and prepare the woman's body for delivery and lactation. The situation is optimal if her body is in excellent general condition, not only during pregnancy but also prior to conception (1). Knowledge of adaptive characteristics is very important in avoiding the treatment of perfectly normal physiological conditions.

Growth of the fetus and enlargement of the maternal body causes weight gain, of which the average is about 20% of the prepregnant weight, the main increase occurring in the second half of pregnancy. The maximal accepted rate of weight gain is 500 g/week during the last weeks of pregnancy (1,2). This increase is due to the conceptus (i.e., placenta, fetus, and amniotic fluid) and maternal components (e.g., uterus, breasts, blood volume, protein, fat storage, and extracellular fluid).

PLACENTAL GROWTH AND FUNCTION

From the very beginning there is an obvious interdependence between the conceptus and the maternal components. When the fertilized ovum in the blastocyst stage reaches the uterine cavity, its external part, the trophoblast, invades the uterine lining. The responsibility for the nutrition of the embryo is now taken over by the trophoblast; previously this function was carried out by secretion within the tube and the uterus. Inside the blastocyst the cells differentiate into embryonic tissue: ecto-, endo-, and mesoderm. For further development to occur, food and oxygen contact with the maternal blood supply is now necessary (3).

At about the twelfth day after fertilization, proliferation of the trophoblastic cells occurs; i.e., the primary villi with their primitive blood vessels

invade the decidual vessels and fetomaternal exchange commences. Branching of trophoblastic cells increases the surface area and the exchange increases (3). In their electronmicroscopic studies, Lee and Yeah (4) have shown that in placentas of small-for-dates (SFD) babies, there is less branching of arteries and veins, which have smaller diameters and H-shaped anastomoses.

The ovum continues to grow; because of lack of space in the decidua, part of the villi atrophies and disappears. The other part, which is in contact with the basal decidua, develops as the fetal part of the placenta (5).

The placenta grows throughout pregnancy, and its weight at term is roughly 500 g; it is not regarded as a simple semipermeable membrane. Transfer of nutrients across the placenta occurs by ultrafiltration, active transport, and diffusion (6). Between the fetal and maternal blood is the placental barrier. Transport of oxygen is mediated by the placenta, and fetal blood has a considerably greater affinity for oxygen than maternal blood. In order to support the fetus under conditions of distress, compensatory hypertrophy of the placenta can occur, for example, in severe chronic anemia and diabetes mellitus (7). Water and electrolyte transport occur by diffusion, and hypohydration or hyperhydration in the mother have a corresponding effect on the fetus. Glucose, as a source of energy, is at a lower level in the fetus than in the mother. The fetus synthesizes amino acids but not gamma globulins, which are transferred from the mother and confer passive immunity on the fetus. Small amounts of free fatty acids cross the placenta and also play an important hormonal and enzymatic function. Transport of fat-soluble vitamins is poor, and their concentrations in the fetus are low (2).

It is known in obstetrics that prolonged pregnancy is associated with a higher incidence of perinatal mortality and morbidity (8). This applies particularly to diabetes mellitus and multiple pregnancy; however, correlations between the changes seen in the maturing placenta and fetal well-being are controversial.

FETAL WEIGHT

Individual variations in fetal weight occur; fetal intrauterine growth and birthweight reflect the quality of the pregnancy. The concept and consequences of intrauterine growth retardation are well known. Fetomaternal circulation and placental transfer are important factors (8). An SFD baby usually has a small placenta, but a small placenta is not necessarily the reason for intrauterine growth retardation (IUGR), provided that the surface area of the villi is sufficient.

There are several factors that can affect the weight of the fetus, for example, the weight and height of the mother and her ethnic group. Indian

women usually give birth to smaller babies (9). In a study of 1,322 births of known gestational age, Grundy et al. (10) found babies of Indian mothers to be approximately 300 g lighter than their Caucasian counterparts. Also, McFadyen and co-workers (11) found the birthweight of Hindus to be about 190 g less than that of Europeans.

The first baby is usually smaller than subsequent offspring, but increasing birthweight in later pregnancies is not always the rule and is not inevitable. Variations in birthweight also depend on such factors as the time interval between pregnancies and probably the ability of the reproductive organs to increase their vascularity (9). Effective digestion and absorption of nutrients and fetomaternal blood flow and placental transfer are all important parameters (8). Inadequate nutrition in poor countries due to faulty eating habits are also important factors (10,11). In a group of Gambian women offered supplementary food 6 days/week during pregnancy, the average birthweight of their offspring was 190 g higher than in the nonsupplement group.

Fetal growth can be monitored by repeated ultrasound examination. This is not usually practicable, however, so maternal weight gain during pregnancy is therefore measured. Failure to gain weight except in the last 3 weeks of pregnancy, particularly when calorie intake is unchanged, suggests that fetal growth may be retarded and requires investigation.

SFD babies are an obstetric problem, and since their condition is poor, there is a high frequency of intrauterine death, intrapartum hypoxia, and handicap (13,14). Such conditions are more common in high-risk patients, such as teenagers, low-economic groups, underweight women, those with poor weight gain, and women with frequent pregnancies. Hence, special medical care must be given in these cases, with efforts made to improve nutritional state (5).

AMNIOTIC FLUID AND UTERUS

Amniotic fluid protects the fetus against possible injury, forms a milieu in which it can move, and provides useful information about fetal health and maturity. Amniotic fluid is produced by cells in the amnion. After the fifteenth week of pregnancy, circulation of the amniotic fluid occurs with ingestion by the fetus and excretion of fetal urine into the fluid. The turnover is approximately 600 ml/hr. The amniotic fluid is 98% water; the rest consists of proteins (but not fibrinogen), carbohydrates, free fatty acids, and hormones (2). The volume of amniotic fluid increases rapidly from an average of 50 ml at 12 weeks of pregnancy to approximately 100 ml at 38 weeks of pregnancy, after which the volume decreases (5). Variations from the normal amount of amniotic fluid often indicate a pathological condition in the fetus (e.g., oligohydramnios in case of IUGR, polyhydramnios in fetal malformation).

The uterus has a unique feature in that it increases from a weight of 70 g (about the size of a pear) to 1,100 g over a period of 40 weeks. It then returns to its approximate initial size within a few weeks postpartum. The hemodynamic changes are extensive—from 9 ml/min/100 g tissue in early pregnancy to 15 ml/min/100 g tissue during the last weeks. This corresponds to a fifteen-fold increase in blood flow (2).

BREASTS AND LACTATION

The breasts increase in size during pregnancy, caused mainly by enlargement of the alveolar glands and, to a lesser extent, by subcutaneous fat. The glandular tissue is divided into 15 to 20 lobes. Each lobe is divided into lobules, which become alveoli (i.e., milk-secreting units). From each lobe there arises a lactiferous duct, which ends in the nipple (15). These changes occur because of increased hormone levels.

High estrogen levels block the production of milk during pregnancy. After delivery, the fall in the estrogen level and the release of prolactin start the production of milk. Stimulation of the local nerve endings by sucking causes higher prolactin secretion, and more milk is produced. Oxytocin causes contractions of the myoepithelial cells, and in this way the milk is transported to the ducts. Human milk consists of protein, carbohydrate, salts, fat, and vitamins and provides on average 70 kcal/100 ml (16).

BLOOD VOLUME

The maternal circulatory system not only promotes the development of the fetus, but also protects the various maternal functions against fetal demands. The most rapid expansion of blood volume occurs during the second trimester, and at 34 weeks of pregnancy reaches a 45% increase over nonpregnant levels (17). It remains at the same level until term and returns to the initial level some 6 to 8 weeks postpartum. The mechanisms producing hypervolemia in pregnancy are not fully understood. They are thought to be caused by rising levels of progesterone and sodium plus water retention.

Despite hemodilution, the increased red cell count due to increased red cell production helps maintain the oxygen-carrying capacity of the blood. Factors influencing the increase in plasma volume are parity, obesity, and multiple pregnancy. The rise in blood volume is closely related to birthweight and placental mass. The probable sites of blood storage are the placenta and uterus, particularly the invervillous spaces, the heart and lungs, and increased venous capacity due to decreased tone. Changes in blood volume during labor and puerperium depend on the degree of muscular activity, dehydration during delivery, and postpartum blood loss (5).

Fluid retention during pregnancy is estimated to be about 8 liters in total.

It is related to salt retention, although there is hormonal control, with involvement of adrenal and placental steroids (2).

NUTRITIONAL REQUIREMENTS

Protein promotes growth of the fetus, placenta, uterus, breasts, and blood cells and the production of milk (15). Total serum protein concentration decreases (mainly albumin) during pregnancy. Endocrine factors may be responsible for these changes, since they are similar to those seen in nonpregnant women who take estrogens. Pregnant women usually accumulate fat (9), which serves as a reserve against nutrient deprivation.

For several years the diets of pregnant women have been the subject of endless discussion, sometimes resulting in confusion, for example, the recommendation to reduce calorie intake to avoid eclampsia (5). A nonpregnant woman requires 2,100 kcal/day, which is distributed as follows:

1,440 kcal/day for basic physiological processes;
360 kcal/day for everyday activities;
150 to 200 kcal/day for work; and
144 kcal/day for specific dynamic actions of food, since metabolism seems to be stimulated by eating.

The total required energy in advanced pregnancy will be around 2,500 kcal/day, increasing to 3,000 kcal/day during lactation (3). A balanced diet has a favorable influence on the health of mother and baby alike.

For many years the calculation made by Hytten et al. (9) of the energy needed for growth of the maternal and fetal components during pregnancy has been accepted. The total energy cost of pregnancy was calculated to be 80,000 kcal. This was the basis for recommending an increased food intake in pregnant women. In a study on healthy, well-nourished Swedish women, Forsum et al. (18) found the calculated average cumulative increase in the maintenance energy cost of a pregnancy to be 25% to 30% higher than the figure of 36,000 kcal quoted by Hytten and Leitch (19) in Oxford. In their multinational studies both Durnin et al. (20) and Lawrence et al. (12) found lower energy requirements for pregnancy. Durnin (20) states that a normal pregnant woman living in an industrialized country does not require an extra intake of food for the theoretical energy cost of pregnancy.

There are probable differences in energy metabolism during pregnancy between populations of women in different nutritional situations. The needs of pregnant women will be guided by various parameters, such as body size, activity, and health status. The opinion of Worthington-Roberts et al. (16) is, "If she is healthy and in good general condition she will not require a lot of additional food, but the quality of it must be high." Further clarification is obviously required.

The concentration of amino acids in the fetus is higher than in the maternal plasma. During maternal protein malnutrition, fetal amino acid supplies are maintained by maternal tissue breakdown. Restriction of protein, calories, or both, during pregnancy may affect fetal growth and development. A comparative study of birthweights of Asian and European babies has shown babies of Hindu vegetarians to be lighter in weight, with a tendency to asymmetrical growth retardation (11).

Fats are an important source of energy; they provide the fat-soluble vitamins and are essential components of cell membranes and the central nervous system. Deficiency is rare. Carbohydrates are also a source of energy, but excessive amounts coupled with low vegetable intake may cause slow intestinal transit and result in constipation or hemorrhoids (15). This is very common in Arabic countries, where women have a high carbohydrate intake. Restriction of carbohydrates is frequently necessary during pregnancy.

Retention of sodium and water is necessary for normal outcome of pregnancy and is maintained by normal renal control mechanisms (i.e., the renin-angiotensin-aldosterone system). Sodium intake should not be restricted in healthy pregnant women. Regulation of sodium intake in preeclampsia does not make any difference to the clinical outcome, and the use of diuretics can worsen the condition, causing electrolyte imbalance and a reduction of blood flow in the placenta. These changes can exert very adverse effects on the fetus and cause neonatal complications, including hyponatremia and polycythemia (5).

Due to hydremia there is a progressive relative decrease in red blood cell count, hemoglobin, and hematocrit during pregnancy. Hypochromic anemia is very common and can occur without clinical signs (15). Owing to the demands imposed by the fetus, maternal requirements for iron increase in the second half of pregnancy (2). The fetus obtains iron preferentially from the mother, even when the mother has severe hypochromic anemia. Fetal iron does not increase if there is a maternal iron overload. Iron transport across the placenta is only from mother to fetus; reverse transfer does not occur. Maternal iron is insufficient to meet the needs of pregnancy, and all pregnant women should therefore be given supplements, particularly after 20 weeks gestation and continued into the puerperium. Each 100 ml of blood loss in connection with delivery means a loss of 45 mg iron.

Trace elements function as cofactors in enzyme systems. Attention has been paid to zinc requirements during pregnancy. Taper et al. (21) studied zinc and copper retention during pregnancy in order to find the amount of zinc and copper intake necessary. Simmer and Thompson (22) found significantly lower zinc levels in pregnant women compared with nonpregnant women. The pregnant women and controls had similar zinc/albumin ratios; i.e., the lower level in mothers could not be explained by decreased concentrations of albumin in pregnancy. There was, however, a significant association between low zinc levels and IUGR. Jameson (23) ardently rec-

ommends zinc supplementation during pregnancy. He has found a high frequency of complications at delivery, such as inefficient labor and atonic bleeding, in women with low and subsequently decreased serum zinc levels during pregnancy. He also points out a possible correlation between maternal zinc deficiency and congenital malformations, as well as long-standing infertility. Abraham et al. (24) were unable to confirm these findings.

Vitamins are involved as enzymes in the metabolism of proteins, carbohydrates, and fats. Intravenous administration of water-soluble vitamins during labor indicates that the placental transfer mechanism favours the fetus; however, this mechanism does not always function properly. In a study of vitamin B_6 status in mothers and newborns (25), it was found that in some newborns a vitamin B_6 deficiency was present despite good maternal status. The importance of vitamin B_{12} and folic acid, accompanied by adequate amounts of protein for the production of blood cells, is well known (5,26). Hibbard et al. (27) have shown an increase in such complications as abruptio placenta, fetal anomalies, and abortions to be due to maternal insufficiency of folic acid. These findings have not been confirmed by other authors.

Howells and co-workers (28) gave Asian women with low plasma retinol concentrations daily vitamin A supplements from 30 weeks of pregnancy to term. This caused a significant increase in maternal, but not cord, blood concentrations. There was, moreover, no effect on the size of the babies. Wild et al. (29) reported a highly significant reduction in the recurrence rate of neural tube defect when periconceptional multivitamin supplements were given.

Another instance where the child is protected against maternal malnutrition has been demonstrated by vitamin studies conducted during lactation. In most cases it appears that the child is favored at the expense of the mother.

The fore milk of 134 women of low socioeconomic background who breastfed for 18 months was examined in connection with vitamin B_2 and B_6 levels. Prolonged lactation did not reduce the vitamin status, although these women rarely increased food intake during pregnancy and lactation (30). Exclusively breastfed infants up to the age of 6 months could maintain their plasma vitamin C levels at equivalent or higher concentrations than a control group receiving formula milk supplemented with vitamin C (31).

CONCLUSION

It would appear that adequate nutrition during pregnancy and lactation is important because of its involvement in the production of energy, synthesis of cells, and regulation of the changed processes in the maternal body. Due to the very complicated structure of human society, however, it has not been possible to make any general recommendations to pregnant and lactating women.

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