

Long-Term Effects of Early-Life Nutritional Status on Development of Obesity in Adulthood

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Abstract. Early-life nutritional status (from conception to 2 years old) has a profound procedural impact on the occurrence of obesity in adulthood. It is a hot research topic in the field of public health and nutrition recently. The traditional view is that adult obesity is mainly caused by unhealthy diet and lifestyle. But recent studies have revealed that intrauterine malnutrition, low birth weight, thinness in childhood, overweight in pregnant women, etc., can destroy adipose tissue, central nervous system and appetite regulation by interfering with insulin and leptin secretion and sensitivity, or induce metabolic enzyme activity changing and hormone axis disorder, which shape the metabolic phenotype of the child generation permanently. The existing results have made it clear that insufficient nutrition or excess in early life can increase the risk of obesity, lipid metabolism disorders and type 2 diabetes in adulthood. However, there are still problems such as insufficient mechanism analysis, insufficient cross-generational effect evaluation, and vague definition of the early intervention window period in the field. It is urgent to integrate multi-group and long-term cohort research to make a breakthrough. The future development direction should focus on building a whole-life cycle health monitoring system and promoting the implementation of individualised nutrition intervention strategies. This article systematically reviews the definition and stage of early life nutrition, the biological mechanism affecting obesity, the specific consequences of different nutritional conditions (inadequacy and excess), relevant influencing factors (such as feeding method, genetics and environment), and preventive interventions.

Keywords: Early-life nutritional status, Childhood, Adulthood, Obesity

1. Introduction

Diabetes is a relatively common chronic systemic metabolic disease. In recent years, the probability of diabetes in adults in China has continued to increase [1]. Diabetes is usually accompanied by many complications, such as hypertension, respiratory diseases and kidney pathological changes, which cause great damage to the patient's body. The traditional view is that diabetes is closely related to eating habits and lifestyles in adulthood. Poor diet such as high sugar, high fat and high

calories and irregular lifestyle such as lack of exercise, smoking, etc. will increase the risk of diabetes.

However, recent studies have shown that malnutrition in early life—from conception to age 2—including intrauterine malnutrition, low birth weight, and childhood wasting, is closely associated with maternal overnutrition, maternal overweight, and an increased risk of diabetes in adulthood. Overweight in pregnant women is closely related to the increased risk of diabetes in adulthood. Early nutritional deficiency or excess in childhood can lead to metabolic abnormalities in adults and increase the risk of lipid metabolism disorders [2]. The nutritional supply during this period will have a long-term and irreversible impact on individual growth and neurological development, and has become a research hotspot in the field of global public health and nutrition.

In recent years, with the improvement of living standards and changes in diet structure, the problem of childhood obesity has gradually increased, and the incidence of diabetes in adolescents has also been on the rise. Therefore, strengthening nutrition management during pregnancy and infancy is of great significance to the prevention of post-adult diabetes. This article systematically summarises the function of key nutrients in early life, foodborne safety risks, differences in feeding methods and their impact on long-term health, and provides a scientific basis for building a whole life cycle health protection system and reducing the burden of chronic diseases in adulthood.

2. The mechanism of affecting obesity in early life

Early life refers to the period from conception to the age of 2, which is in a critical period for the growth and development of the body, providing rich nutrition, which can ensure the healthy growth and development of the body and reduce the probability of some diseases after adulthood. Among them, macronutrients, trace elements and other active nutrients play an important role in early life nutrition.

At present, it is believed that malnutrition and overnutrition in early life can lead to obesity. The mechanism may be: the destruction of organ function leads to abnormal secretion and sensitivity of hormones such as insulin and leptin, resulting in disorders of adipose tissue, central nervous system and appetite regulation, metabolic enzyme disorder, or hormone axis disorder. It will affect the secretion of insulin. In order to regulate and increase the secretion of glucocorticoids that antagonise insulin, the body will cause irreversible damage to the body. Studies show that intrauterine malnutrition can permanently damage liver cells, resulting in a decrease in the activity of some enzymes, such as glucokinase and glycogen synthase, thus affecting the synthesis and utilisation of glucose in the body [2].

In the foetal period, the sensitivity of pancreas, pancreatic islet β -cells and insulin receptors can be affected by malnutrition and low BMI during pregnancy, which leads to abnormal mechanisms in the body. The fetus can adapt to adverse environments by reducing its own metabolism and energy demands, which lays the groundwork for metabolic problems in adulthood [1].

In the infant stage, breast milk is the earliest nutrient to be exposed to infants and young children. Breast milk is rich in protein, lipids and carbohydrates and a variety of immunomodulatory factors, which have a great impact on the health of infants and can enhance the immune system of infants and young children. At the same time, studies show that appropriately extending the time of breastfeeding can effectively reduce the incidence of obesity in adulthood.

The nutritional status of early life (from conception to 2 years old) has a profound procedural impact on the occurrence of obesity in adulthood, and is a current research hotspot in the field of public health and nutrition. The traditional view is that adult obesity is mainly caused by poor diet and lifestyle, but recent studies have revealed that intrauterine malnutrition, low birth weight,

childhood wasting, pregnancy overnutrition, overweight in pregnant women, etc., can effectively reduce the incidence of obesity in adulthood.

3. Impact of different nutritional status on adult obesity

3.1. Impact of malnutrition on adult obesity

According to the thrifty phenotype hypothesis, inadequate intake of protein, total energy, essential fatty acids, and various micronutrients during pregnancy can impair placental nutrient transfer function, disrupt critical developmental windows for endocrine organs and adipose tissue, and induce a metabolism-oriented "energy-saving" phenotype in the fetus. Given that it is in a state of nutritional deficiency within the womb, the baby will reduce energy consumption and store fat. If a person eats a high-calorie diet for an extended period after birth, they may be prone to gaining a large amount of fat and face a higher risk of central obesity (Table 1).

Nutritional deficiency in the first trimester of pregnancy, for instance, may fail to provide enough protein and energy for fetal growth, thus increasing the risk of low birth weight [3]. Animal studies have shown that the offspring of pregnant mice on a low-protein diet are significantly lighter at birth than those from the control group; they also develop abnormal increases in body weight and fat content during adolescence and have been linked to adult obesity [3]. Population-based studies show that people who experienced famine early in life are at a higher risk of obesity later in life, especially those who suffered from malnutrition during pregnancy [4].

Table 1. Mechanisms and outcomes of early-life nutritional status affecting adult obesity

Nutritional Status	Specific Exposure Conditions	Core Programming Mechanisms	Adult Obesity Outcomes	Ref
Intrauterine malnutrition	Low protein/caloric intake or famine during pregnancy	Impaired placental transport; energy-saving phenotype; enhanced fat storage capacity	Adult central obesity (OR 1.218–6.20)	[3-5]
Low birth weight	Fetal growth restriction	Endocrine axis dysregulation; abnormal insulin/leptin sensitivity	Abnormal adolescent body fat gain; elevated adult TG and TC	[3, 5]
Maternal overnutrition	High-fat/high-sugar diet during pregnancy	Synchronized increase in adipocyte number and volume; impaired white adipose browning	Macrosomia; childhood obesity tracking into adulthood; resistant obesity	[3, 6, 7]
Childhood obesity (continuation)	Continued excess during lactation + childhood	Adipocyte elevated gut F/B ratio (energy extraction ↑12%–16%)	>70% track to adulthood; metabolic syndrome and T2DM comorbidity	[3, 4, 6, 7]

3.2. Increased risk of obesity in adulthood

Multiple cohort studies have found that people who were malnourished in their early years, such as famine exposure or being born underweight, have a much higher risk of obesity and metabolic syndrome later in life; the odds ratios (OR) in these studies are between 1.218 and 6.20 [5]. Animal experiments have also added to this: offspring of mothers who were nutritionally deficient during gestation showed higher serum triglycerides (TG) and total cholesterol (TC), lipid metabolism disorders, and a significantly increased risk of obesity compared with offspring of normally

nourished mothers [3]. In addition, when early-life malnutrition is followed by a high-calorie diet in adulthood, a "double-hit" effect occurs and the risk of obesity is further increased [6].

The double-hit hypothesis provides a reasonable explanation for the increased risk: the first hit is damage to metabolic programming caused by fetal undernutrition, and the second hit is an unhealthy adult lifestyle, such as a high-fat and high-sugar diet and sedentary behaviour. Together, the two factors are likely to be in harmony and thus may increase the risk of obesity by as much as three times. Gut microbiota studies have shown that malnourished offspring in utero exhibit altered microbial composition; specifically, they have a relatively high Firmicutes/Bacteroidetes ratio. Therefore, there will be a 12%–16% improvement in the efficiency of energy extraction from food and a larger caloric surplus at the same food intake, thus promoting fat accumulation.

3.3. The impact of excessive nutrition on adult obesity

Too much food during pregnancy can increase the risk of macrosomia (birth weight of 4 kg or more) and is also linked to obesity in childhood [7]. Childhood obesity shows strong trajectory continuity, and more than 70% of obese children remain overweight or obese during adolescence and develop adult obesity [7]. Studies on animals have shown that a high-fat, high-sugar diet during lactation increases damage caused by excess nutrition in utero and prolongs the period of early-life exposure to high-calorie diets throughout development. Research has shown that a high-fat diet in mothers during lactation leads to a synchronous increase in both the volume and number of adipocytes in offspring, and visceral fat proliferation activity is 50% higher in these offspring compared to controls. At the same time, the browning pathway of white adipose tissue is also suppressed, resulting in a permanent reduction in fat oxidation and breakdown capacity; thus, a metabolic state of "easy storage, difficult breakdown" has been established and a histological basis for adult-onset obesity has been laid [3].

3.4. Persistent obesity into adulthood

Childhood obesity exacerbates metabolic disorders and results in prolonged, aggravated obesity later in life [7]. At the same time, metabolic disorders caused by overnutrition in utero are often permanent; even if a person reduces their food intake later in life, the risk of obesity and other metabolic diseases remains high [3]. Based on epidemiological data, people who have experienced overnutrition in early life are more likely to be obese or have type 2 diabetes later in life [4].

4. Factors influencing the relationship between early-life nutrition and adult obesity

There is a close relationship between nutrition conditions in early years and obesity in adulthood. Fetal period, infancy, and early childhood are crucial states for the human body's development. At these periods, not only could nutrition intake impact the body's development, but also have further and deeper influences on metabolic functions after being an adult.

To begin with, the risk of obesity at adulthood is increased due to both overnutrition or insufficient nutrition intake during early years. As Thompson states in his article, infants would form a nutritional pattern called "thrifty metabolism" when there is insufficient nutrition to intake, which leads to an easier storage of fat in adulthood under conditions where sufficient food is provided. By contrast, if the mother takes in too much sugars and fat during pregnancy, the infants would also get too many fat cells and make them have a higher possibility to become fat in the future [7]. Moreover, adulthood obesity is strongly related to feeding patterns in early years as well.

Breastfeeding could help regulate infants' appetites, and decrease the risk of obesity after adulthood. However, unhealthy dietary patterns would be easier to form by adding high sugar and fat contents in early periods' feeding [7].

In addition, development of obesity could also be affected by genetic factors, family environment, and lifestyle behaviors. Factors that could further increase obesity risk are lack of physical activity, excessive consumption of high-calorie foods, and irregular sleep patterns [7].

5. Prevention and intervention strategies

Prevention of adult obesity should be started at the early years of life. Strategies for pregnant women include maintaining balanced diets, managing appropriate weight ought to be conducted [8]. On one hand, from the perspective of infant feeding, strategies could be using breastfeeding methods, limiting sugar and fat content intake. Also, parents should consider carefully about the amounts and types before giving complementary foods to their babies [9]. In childhood, health education should be given appropriately. Factors that could lead to obesity such as prolonged sitting or long screen time could be avoided by developing the good habits of exercising regularly [9]. On the other hand, from a higher perspective, governments and communities also play significant roles. Activities or podcasts about nutritional education and healthy lifestyle diets should be encouraged. Through early nutritional interventions and continuous health education, the risk of obesity and other chronic diseases in adulthood can be effectively reduced [9, 10].

6. Conclusion

The impact of early life nutrition on adult obesity risk has been demonstrated in the research. From conception to two years of age is a critical stage of development. Poor maternal nutrition or abnormal maternal BMI in pregnancy can influence fetal development and induce metabolic changes that increase the risk of obesity later in life. Studies also show that breastfeeding is associated with healthy appetite regulation and reduced risk of obesity later in life. Studies have shown that undernutrition and overnutrition in early life can increase the risk of obesity in adults, metabolic syndrome and other metabolic disorders. Childhood obesity can often carry on into adulthood and long-term health outcomes can be further influenced by factors such as feeding practices, genetics, family environment and physical activity. The available evidence indicates that obesity prevention is best accomplished by a balanced diet during pregnancy, promotion of breastfeeding, proper introduction of complementary foods, and promotion of physical activity during childhood.

Additional research is needed to better understand the influence of early life nutrition on health throughout the lifespan. Large-scale studies and advances in areas such as metabolism and gut microbiome research may aid in identifying high-risk populations and the optimal time for intervention. Prevention activities should also include nutrition, health education and lifestyle support. Greater collaboration among healthcare providers, communities and policymakers may help to reduce the prevalence of obesity and improve long-term health outcomes. Therefore, comprehensive intervention strategies targeting the first 1000 days of life should become the core of public health policy, while integrating the synergistic efforts of families, schools, and healthcare systems. Future research also needs to explore epigenetic mechanisms to reveal how nutritional exposure long-term affects metabolic programming.

Author contribution

All the authors contributed equally and their names were listed in alphabetical order.

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