

The Effects of Protein on Infant Growth and Nutritional Health

Ziyan Zhang

*Col of Agricultural & Life Sci, University of Wisconsin-Madison, Madison, USA
quella_zzy@foxmail.com*

Abstract: Protein is a critical nutrient for infant growth and development and plays an essential role in maintaining their nutritional health. With the advancement of nutritional science and increased attention to infant well-being, the types and quality of protein have garnered widespread interest. This paper primarily introduces the sources and composition of protein intake in infants. Drawing upon existing literature, it reviews the relationship between protein and various aspects of infant development, including physical growth, micronutrient metabolism, immunity, gastrointestinal health, and sleep function. The aim is to provide a theoretical foundation for scientific infant feeding, and to present insights into the functions of protein and feeding strategies. The findings offer valuable guidance and reference for promoting the healthy development of infants.

Keywords: Protein, Infants, Growth and Development, Nutritional Health, Immunity

1. Introduction

Protein is an indispensable nutrient for infant growth and development. The infant stage (0–2 years old) represents the most rapid period of physical development in a human's life. During this crucial phase, the nutritional status of protein not only directly influences an infant's physical and brain development, but also exerts long-term effects on adult health and potentially on lifelong well-being [1]. Breast milk is the most ideal natural food for newborns, providing both essential nutrients and enhanced immunity. The World Health Organization recommends exclusive breastfeeding for the first six months of life [2]. The high-quality proteins in breast milk promote the development of muscles, bones, and the brain. In contrast, inadequate protein intake can slow growth rates and reduce immune function, among other issues. Thus, investigating the role of protein is critical for early intervention in promoting infant health and development.

In recent years, numerous studies have explored the relationship between protein and infant health. For example, Strzalkowski and colleagues examined the drawbacks of many commercial infant formulas, noting that excessive protein content may increase the risk of childhood obesity [3]. Perrella et al. studied the macronutrients and micronutrients in breast milk—such as carbohydrates, lipids, and vitamins—highlighting their roles in promoting growth, immune maturation, neurodevelopment, and metabolic health [4]. Embleton et al. focused on the impact of protein on the health of preterm infants, emphasizing the importance of multi-nutrient interventions [5]. Lee and colleagues explored the role of the milk fat globule membrane (MFGM) in infant gut health and metabolism. Their research indicated that MFGM, when added to infant formula, could significantly reduce metabolic and microbiota differences between breastfed and formula-fed infants, suggesting its potential as a

beneficial intervention for non-breastfed babies [6]. However, most current studies focus on single protein sources or short-term outcomes, often overlooking the broader and longer-term effects of protein on infant growth and health—especially regarding risks for metabolic disorders later in life.

This paper aims to provide a comprehensive review of the effects of protein on infant growth and nutritional health. Drawing on recent clinical evidence and nutritional research, it analyzes strategies for optimizing protein sources, intake levels, and composition. Special attention is given to the functional components of protein—including micronutrients, immunoglobulins, and protein hydrolysates—and their impact on infant development and physiological functions. The findings of this study can serve as a scientific basis for infant nutrition practices, food product development, and public health policy, ultimately contributing to improved health outcomes for infants.

2. Sources and composition of protein intake in infants

Protein is an essential component of the infant body. When energy is insufficient, protein can be automatically broken down to supply energy. The primary source of protein for infants is breast milk, which is considered the most suitable food for infants (as shown in Fig. 1). However, in cases where breastfeeding is difficult or breast milk is insufficient, formula milk is often chosen as an alternative. Formula is made from cow's milk or goat's milk that has been sterilized, defatted, dehydrated, and dried, making it another major source of protein for infants. Breast milk and formula differ in composition, which results in differences in nutritional health outcomes. Breast milk typically contains about 1–2% protein, mainly consisting of 60–80% whey protein, 20–40% casein, and 1–4% milk fat globule membrane (MFGM) protein. The primary whey proteins in breast milk include α -lactalbumin, lactoferrin, lysozyme, and immunoglobulin A (IgA), while in cow's milk, β -lactoglobulin is the main component. Due to differences in acid solubility, whey protein and casein in breast milk can be distinguished. Breast milk contains α S1-, β -, and κ -casein, with κ -casein accounting for about 70% and being a highly glycosylated, crucial protein. Cow's milk also contains the aforementioned three caseins, along with α S2-casein [8]. Moreover, micronutrients affect protein absorption. Breast milk contains higher levels of copper and selenium, whereas levels of calcium, phosphorus, potassium, and sodium are significantly lower than in cow's milk [9]. The amino acid content also varies between the two. Infant formula contains 12 hydrolyzed amino acids, with most concentrations similar to those found during the first two months of lactation (1–60 days), but higher than those during the latter four months (61–180 days). This is because the amino acid content in breast milk undergoes dynamic changes throughout the lactation period (1–180 days) [10].

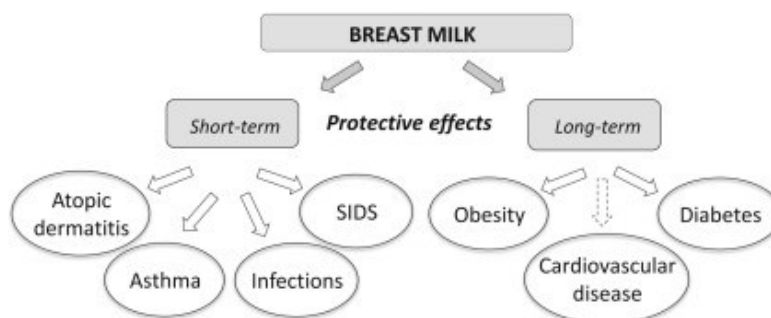


Figure 1: The short and long term protective effects from breast milk [7]

3. Effects of protein on infant growth and nutritional health

3.1. Effects of protein on infant growth and development

Protein plays a crucial role in infant growth and development, cognitive enhancement, disease resistance, and overall physical fitness. Protein intake promotes the synthesis of amino acids in infants, which in turn stimulates the secretion of insulin and insulin-like growth factor 1 (IGF-1). These growth factors promote infant development and fat generation, with one of the most evident effects being weight gain. Increased weight may indirectly facilitate organ growth to support higher metabolic demands. In addition to fat tissue, protein also contributes to the development of other organs. Studies show that early protein supplementation helps improve brain, heart, and other organ functions in infants [11]. However, both deficiency and excess intake of protein can negatively affect growth. Protein deficiency can lead to growth retardation, malnutrition, and damage to internal organs. Such infants may suffer from emaciation due to the loss of subcutaneous fat, making them more susceptible to infections. Malnutrition can also suppress insulin production and reduce protein synthesis, resulting in hypoproteinemia, impaired immune function, edema, and diarrhea [12]. Moreover, numerous observational studies suggest that when protein intake exceeds metabolic demand, infant body weight increases rapidly, potentially elevating the risk of obesity later in life. This is due to a positive correlation between protein intake and the risk of overweight and obesity; excessive protein increases the concentration of circulating branched-chain amino acids (BCAAs) and other essential amino acids, leading to fat accumulation [13]. Additionally, as infant kidneys are still developing, excessive protein intake may increase renal burden and potentially impair future kidney function [11].

3.2. Protein facilitates the absorption of micronutrients in infants

From the immune system to the digestive system, micronutrients (minerals and vitamins) support healthy growth in infants and help prevent various deficiency-related diseases. For infants, breast milk is undoubtedly the best source of micronutrients. Although minerals do not provide energy, they play a vital role in health and development. After protein in breast milk is broken down, it releases amino acids such as histidine, cysteine, cystine, glutamic acid, and methionine. These amino acids bind with zinc to release it from insoluble complexes, thereby enhancing absorption. Similarly, cysteine, histidine, lysine, and cystine can also increase the bioavailability of iron [14]. Minerals contribute to the development of strong bones and the transmission of neural signals [15]. As for vitamins, certain proteins function as emulsifiers during digestion, aiding vitamin absorption. According to research by Lindahl et al., vitamin D3 forms complexes with proteins that have greater solubility and are more easily absorbed [16]. Studies by Lodge et al. suggest that milk-derived proteins may enhance vitamin E absorption by improving micellar formation [17].

3.3. Immunoglobulins and protein hydrolysates enhance infant immunity

Immunoglobulins (Ig) are antibodies synthesized by plasma cells from B lymphocytes. They are found in body fluids and on the surface of some cells, capable of recognizing various specific antigenic determinants and forming the basis of humoral immunity [18]. Immunoglobulins consist of four polypeptide chains linked by disulfide bonds. Based on the structure of the heavy chains and the polymeric assembly, there are five types of immunoglobulins in the human body: IgG, IgM, IgA, IgD, and IgE [19]. During pregnancy, mothers can transfer IgG to the fetus via the placenta. In animals, newborns gain immunity by ingesting colostrum rich in IgG. During lactation, IgA in breast milk can reduce the incidence of necrotizing enterocolitis in infants [20]. Additionally, infants may receive intravenous immunoglobulin to enhance immunity and prevent conditions such as immune hemolytic

disease and thrombocytopenia [21]. Protein hydrolysates mainly consist of peptides and amino acids. To prevent allergic reactions, hydrolyzed formulas are often used for infants. For example, milk protein is a common allergen that can cause eczema in infants. However, clinical observations show that hydrolyzed formula can reduce eczema. This is because chemical and enzymatic hydrolysis reduces the molecular weight and peptide chain length of milk proteins, thereby minimizing potential allergens [22].

3.4. Protein and gastrointestinal health in infants

Protein is vital to the gastrointestinal health of infants. Infancy is a key period for the formation of gut microbiota, and the gastrointestinal tract is quickly colonized by microbes after birth. From 0–1 years old, the composition and diversity of the gut microbiota undergo significant changes (as shown in Fig. 2). Among the influencing factors, breast milk plays a primary role in the development of infant gut microbiota [24]. Protein provides energy for microbial growth. Additionally, membrane proteins, whether glycosylated or not, interact functionally with bacteria [25]. Intake of high-quality protein promotes the growth of probiotics. Guerin et al. found that the milk fat globule membrane can serve as a probiotic carrier, facilitating the survival and function of beneficial bacteria in the gut [26]. Studies also show that mucin released during milk protein digestion exhibits diverse biological activity in the gastrointestinal tract [27]. Moreover, immature digestive systems in infants hinder food digestion and absorption. According to experiments by Veronica et al., hydrolyzed proteins in formula milk alter stool consistency. Protein helps accelerate gastric emptying, enhances gastrointestinal motility, and softens stools [28]. Therefore, protein plays a key role in maintaining gastrointestinal health in infants.

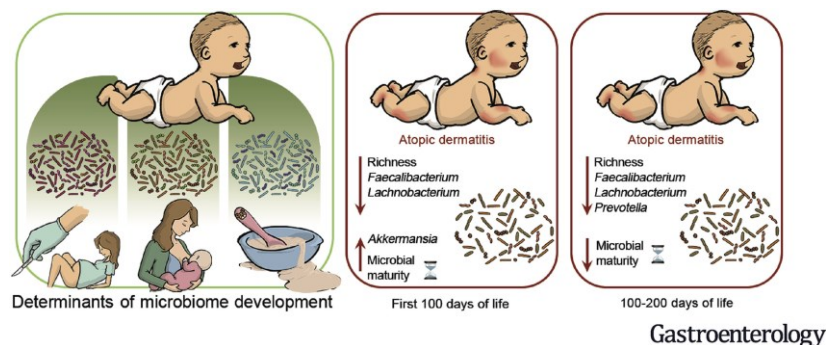


Figure 2: Graphical abstract of microbiota development with infant age [23]

3.5. The role of protein in infant sleep patterns

For parents, sleep disturbances in newborns are a major concern. Although Barbara et al. found that infants sleep an average of 12.8 hours at night (as shown in Fig. 3), frequent nighttime awakenings raise concerns about infant sleep quality. Their data also showed a negative correlation between night awakenings and age [29]. Sleep issues in infancy can lead to problems with weight and socio-emotional development later in life [30]. Protein plays an important role in regulating sleep patterns. α -Lactalbumin provides tryptophan and lysine, with tryptophan helping infants fall asleep faster and improve sleep quality [31]. Experiments show that high concentrations of tryptophan reduce sleep latency due to its breakdown into melatonin, which stabilizes sleep [32]. Additionally, protein is a major energy source for infants. Sufficient protein intake helps maintain stable blood glucose levels, reducing sleep interruptions caused by hunger. Therefore, protein intake can effectively improve sleep in infants.

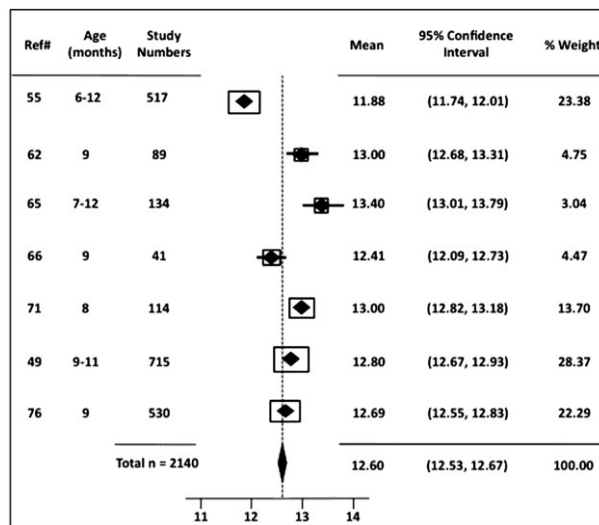


Figure 3: A meta-analysis from 7 studies on 9 month infants to estimate the average time of sleeping duration [29]

4. Conclusion

Protein plays a crucial role in the growth, development, and nutritional health of infants. Based on a review and analysis of existing literature, this paper summarizes the key effects of protein on infants. Breast milk is the primary source of protein for infants, contributing significantly to the development of their bodies, organs, and skeletal systems. An adequate intake of protein has a positive impact on enhancing infants' physical fitness. In terms of nutritional health, protein facilitates the absorption of micronutrients, including trace elements, by infants. It also aids in the gastrointestinal absorption of vitamins. Furthermore, immunoglobulins and protein hydrolysates can help prevent allergic diseases and inflammatory conditions in infants, thereby playing an essential role in safeguarding infant health. Proteins found in breast milk and other sources promote the growth of gut microbiota, enhancing intestinal activity and maintaining gastrointestinal health. Lastly, protein also contributes to improved sleep in infants by helping them fall asleep faster and alleviating sleep disturbances. In summary, protein supports infant growth and nutritional well-being through multiple pathways: promoting physical development, enhancing micronutrient absorption, boosting immunity, improving gastrointestinal health, and regulating sleep patterns. Thus, protein has a comprehensive and positive impact on infant growth and overall health.

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