Protein intake and obesity in young adolescents (Review)

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Abstract. The abundance of protein and its functional diversity in living systems makes it essential for virtually all life processes. Dietary protein and amino acid requirements are affected by age, body size, body composition, physiological state, and the level of energy output. The requirement for dietary protein is based on the indispensable amino acids under all conditions and under specific physiological and pathological conditions as well as the synthesis of dispensable amino acids and other nitrogen-containing compounds. Previous findings have shown the influence of early intake of proteins on the development of overweight in healthy children. The present review focused on the possible association (if any) between protein intake and later development of obesity. The aim is to benefit physicians, dieticians as well as parents to understand future consequences of incorrect dietary habits in young adolescents and encourage healthy dietary habits to avoid obesity.

Contents

1. Introduction

Protein intake during childhood has a paramount effect on growth and development (1). It is an essential macronutrient necessary for building and repairing tissues, defending the immune system, coordinating cell activity, serving as a catalyst, and providing energy. Factors including food availability and absorptive capacity affect the quantity and quality of a child's intake of protein. Animal sources of dietary protein include meat, eggs, cheese, fish, and dairy (2). Protein is also found in plant products such as nuts, seeds, grains, legumes, beans, and vegetables. In general, animal protein varies from plant protein in that it has higher saturated fat content and contains cholesterol. Plant protein is higher in fibre and carbohydrates (3). Vegetarian diets, which are typically high in plant proteins, are associated with health advantages such as lower blood cholesterol levels, lower risk of heart disease, lower body mass index (BMI), lower overall cancer rates, lower blood pressure levels, and lower risk of hypertension and type 2 diabetes (4).

Scoring systems have been developed to determine the quality of a dietary protein source by quantifying the amino acids profile (5). The protein digestibility-corrected amino acid score (PDCAAS) is a measurement of the protein quality in human nutrition (6). The higher the PDCAA score, the higher the amino acid profile and quality of protein. Animal proteins (i.e., egg) and purified plant proteins (i.e., soy) have higher scores than plant proteins (i.e., wheat) with intact cell walls. Previous studies focusing on overall protein intake during infancy and early childhood showed that a high protein intake (>15% of energy) during early childhood may increase the risk of obesity. Furthermore, high protein intake during certain periods of childhood (12 months, 18-24 months, and 5-6 years) results in an increased BMI in subsequent years and even into adulthood. A child with a high BMI-for-age percentile has an increased risk of being overweight or obese in adulthood (7-10). The present review article primarily focused to impart knowledge pertaining to crucial relationships among protein intake and future aspects of incorrect dietary inputs based on quality, quantity and time of protein intake. The review covered important aspects essential for the proper diet of young adolescents in order to secure their future from the lethal effects of obesity.

2. Protein load and obesity

The 'early protein hypothesis', initially identified by Rolland-Cachera, suggested that a high protein intake in early infancy increases the risk of obesity (11). Infancy and early childhood protein intakes are of interest because of differing macronutrient distribution found in infant formula versus human milk and the stimulating effect protein has on

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insulin-like growth factor-1 (IGF-1) and insulin secretion (12). Insulin and IGF-1 have anabolic effects that stimulate growth in children. Higher concentrations are found in infants fed formula compared to infants fed human milk. However, children breast-fed during infancy are taller and have higher IGF-1 concentrations later in life (13). A low IGF-1 concentration later in life is associated with increased risk of non-communicable diseases (NCDs) facilitated through IGF-1. There is a concern that high protein intakes during the first years of life may cause obesity later by altering IGF-1 concentrations.

It is thought that infants experience a rapid increase of protein intake when transitioning to solid foods, typically 3- to 4-fold greater than the physiological requirements of the average infant (14). The protein energy percentage is 7-8% in infant formula, 20% in full fat cow's milk, ~5% in breastfed infants, and 15-20% in the typical family diet. In turn, breast-fed infants are shorter, weigh less, and have a lower BMI than formula-fed infants. Furthermore, an inverse relationship between IGF-1 measured in infancy and in late adolescence has been identified. The type of protein consumed may have different effects on IGF-1. For example, it has been shown that early intake of cow's milk increases linear growth in well-nourished populations by stimulating circulating IGF-1 (15). The risk factor for NCDs later in life is associated more with a poor protein quality intake with no animal protein than with high intakes of total protein. A systematic literature review conducted by Hörnell *et al* (10) aimed to assess the health effects of different intakes and sources of protein (animal- or plant-based) in infancy and childhood in a Nordic setting (10) The above systematic review concluded that a high intake of protein in infancy and early childhood is associated with an increased risk of obesity later in life.

A review by Martorell *et al* (16) examined the relationship between overall nutrition in early life and the development of adiposity later in life. Three hypotheses were posited: i) overnutrition increases the risk of later obesity; ii) undernutrition is associated with increased risk of obesity; and iii) optimal nutrition during infancy, the gold standard being breastfeeding, is protective against future obesity. Possible mechanisms for these outcomes include disruptions in organ function, increase in the number and/or size of fat cells or alterations in adipose tissue function, and dysfunction of the central nervous system resulting in appetite regulation disturbances. The authors of that study (16) reviewed observational, experimental, and quasi-experimental studies. Birth weight and adult BMI were used to indicate the influence of fetal nutrition on adult obesity. The results from those studies are conflicting. Some studies (17,18) identified a J-shaped relationship between birth weight and adult BMI, while others only found an association between high birth weight and increased adult BMI. A majority of the studies (19,20) found that higher birth weights, particularly birth weights >10 pounds, led to increased obesity in adulthood. In addition, intrauterine overnutrition is associated with a greater risk of obesity and may play a role in childhood obesity.

A longitudinal study conducted by Gunther *et al* (21) examined whether certain time points or periods of protein intake in infancy, early childhood, or the preschool years contribute to BMI at 7 years of age, and whether the association is attributed to distinct protein sources (animal, vegetable, dairy, meat, or cereal protein). The aim of that study was to investigate the validity of the early protein hypothesis, which suggested that high protein intake during infancy increases the risk of obesity later in life. The early protein hypothesis is based on the consideration that infant formula has significantly higher protein content than human milk and that children experience a rapid increase in protein intake when transitioning to solid foods. Previous studies (22,23) have failed to investigate whether distinct protein sources are associated with the early protein hypothesis. The study population was derived from the DONALD study (24), an ongoing cohort study that follows subjects through young adulthood. An average of 40-50 infants from Dortmund, Germany were recruited on an annual basis and examined at the age of 3-6 months. Up until early adulthood, investigators intermittently collected information from participants on nutrition, growth, metabolism, and health status. A similar prospective study by Scaglioni *et al* (8) examined the effects of the early intake of macronutrients on the development of overweight in healthy children.

Skinner *et al* (25) examined longitudinal growth and energy intake in children aged 2-8 years and identified factors associated with the children's BMI. Weight, height, and BMI percentiles were determined based on the Center for Disease Control (CDC) growth charts. Dietary intakes from 3-day food records were averaged and analyzed using Nutritionist IV, version 3.5 (Axxya Systems LLC, Stafford, TX, USA). Each child was assessed 15-17 times by the end of the study and additional behavior information was obtained at certain time points. Dietary fat and dietary protein had a positive relationship to BMI whereas a negative association was identified with dietary carbohydrate intake. The findings suggested that childhood obesity is multifactorial and impacted primarily by BMI. Thus, the quantity and quality of protein intake during childhood affects BMI and body fat percentage (BF%) subsequently in life.

3. BMI and obesity

Children with a higher BMI-for-age and children who subsequently became obese ages had a greater risk of adult obesity. Childhood obesity also increases the risk of developing morbidities in adulthood. In a review, Maffeis and Tatò (26) addressed the association between childhood and adult obesity and the effects of childhood obesity on morbidity and mortality. Rates of diabetes, coronary heart disease, atherosclerosis, hip fracture, and gout were increased in individuals who were overweight as adolescents. Moreover, cardiovascular risk factors such as total blood cholesterol, blood low-density lipoprotein- and high-density lipoprotein-cholesterol, and blood pressure levels and being overweight continued from childhood into adulthood. High BMI-for-age values can be a useful tool in identifying children and adolescents at increased risk of becoming overweight or obese in adulthood. Furthermore, dietary factors such as protein sources affect childhood obesity and should be examined as potential contributors in the development of morbidities in adulthood. Identifying dietary intake markers for increased BMI in children may assist with the development of dietary recommendations that may decrease the risk of developing obesity as an adult. For example, if a high intake of animal protein

Table I. Advantages and disadvantages of dietary assessment methods.

Dietary assessment	Method	Advantages and disadvantages
Food record	Frees participants from relying on memory	Sets a burden on participants
	Includes a specific time period	Proposes a challenge for participants to record foods not consumed within the home
	Allows investigators to be trained in groups	Alters dietary habits of participants in some cases
	Offers absolute and relative intakes	Requires participants to have literacy and numeracy skills
		Proposes a high cost
		Challenges feasibility for large studies
		Proposes a burden on participants due to necessary multiple records
24-h recall	Frees participants from requiring literacy or numeracy skills	Requires participants to rely on memory for recall
	Allows dietary habits of participants to be left unaltered	Proposes a challenge for estimating food quantity
	Provides a low burden for participants	Requires training of investigators
	Provides a quick assessment	Proposes a high cost
	Includes a specific time period	Challenges feasibility for large studies
	Offers automated data entry	Proposes a burden on participants due to necessary multiple records
Food frequency questionnaire (FFQ)	Allows dietary habits of participants to be left unaltered	Requires participants to rely on memory for recall
	Offers a low burden for participants	Requires participants to have literacy and numeracy skills
	Frees the training of investigators	Proposes a challenge for estimating food quantity
	Allows administration in multiple formats	Bypasses food descriptions
	Offers a quick and inexpensive assessment	Bypasses assessment of meal patterns
	Allows automated data entry	Limits data when FFQ is nutrient specific
	Allows practicality for large studies	
	Offers assessment of total diet and select nutrients	
	Offers assessment of current or past diet	
	Allows participants to be divided into groups based on intake	
Targeted diet and/or behavior assessments	Allows dietary habits of participants to be left unaltered	Requires participants to rely on memory for recall
	Provides a low burden for participants	Requires participants to have literacy and numeracy skills
	Allows practicality for large studies	Requires research before developing assessment
	Offers a simple and inexpensive assessment	Challenges validity
	Allows automated data entry	Bypasses the collection of of nutrient intakes
	Allows trends to be monitored	Limits food intake information
	Allows behaviors and environmental information to be assessed	

compared to plant protein predisposes children to obesity, dietary recommendations for increasing plant protein intake and decreasing animal protein intake may be developed. In the case that high intakes of animal protein is associated with a high BMI in children, parents can intervene during early childhood by providing adequate amounts of animal and plant protein for proper growth and weight maintenance. To ensure that healthy children are raised into healthy adults, it is important for the public to be aware of contributing factors to obesity.

4. Multi-factorial aspects of obesity

Previous findings have shown that the association between dietary inputs and resultant obese conditions in children are multi-dimensional or multi-factorial in nature. Possible mechanisms for the future outcomes of incorrect dietary habits include disruptions in organ function, increase in the number and/or size of fat cells or alterations in adipose tissue function, and dysfunction of the central nervous system resulting in appetite regulation disturbances. A majority of the studies

found that higher birthweights, particularly birthweights >10 pounds, led to increased overweight and obesity in adulthood (21). A proportion of the causes of high birthweight may be attributed to early exposure to famine or gestational diabetes. The fetuses of mothers with diabetes are exposed to high concentrations of blood glucose, which leads to hyperinsulinemia and increased growth of fat, lean body, glycogen stores, and overall birth weight.

On the other hand, increased risk of overweight and obesity from undernutrition is not well understood and contradictory. However, it has been suggested that individuals whose nutrient intake is scarce early in life move to abundance or excess in adulthood. In addition, intrauterine overnutrition is associated with a greater risk of overweight and obesity and may play a role in childhood obesity. A longitudinal study conducted by Günther *et al* (21) evaluated whether certain time points or periods of protein intake in infancy, early childhood, or the preschool years contribute to BMI at 7 years of age, and whether the association is attributed to distinct protein sources (animal, vegetable, dairy, meat, or cereal protein). A previous study (8) confirmed an additional time period (5-6 years of age) as a sensitivity period of total and animal protein intakes for later body obesity. Thus, the quantity and quality of protein intake during childhood affects BMI and BF% in subsequent years. Future studies are needed to compare protein intake later in childhood and BMI as predictors for adult obesity.

5. Importance of dietary intake assessment in children and young adolescents

Assessing dietary intakes in children is a challenging aspect of nutrition research. Erroneous methodology often limits dietary intake data in outcome evaluations. However, this information is essential for advancing dietary recommendations for overweight and obese children (27). Selection of the appropriate measuring tool or method for dietary intake in children proposes a challenge in itself, whether it is a total diet assessment, a targeted diet, or related behaviours assessment. Each method depends on the dietary features of interest and the characteristics of the study population. The weight status of subjects and study design are important factors when selecting an appropriate methodology for dietary assessment (13,21).

Dietary studies on children and adolescents have identified a positive association between under-reporting and increased body fatness. Collectively, reports from large-scale surveys have shown a decrease in energy intake over time despite weight gain worldwide, suggesting energy expenditure has decreased and/or measurements of dietary intake are flawed (28). One cross sectional study examined the extent of under-reporting of energy intake in children between the ages of 4-18 years (29) The results of that study showed that the target group is also a critical element when selecting a dietary intake method.

Different age groups have varying literacy and numeracy skills, memory capabilities, attention spans, and cognitive abilities. For example, children <8 years of age have limited competency in providing an accurate dietary recall and children <10 years of age lack the conceptual skills required for reporting usual intake, serving sizes, and frequency of behaviors. Thus, assessing dietary intake in children <10 years requires parental involvement. The dietary habits and level of structured eating environment should also be considered for different age groups, as older children tend to consume more meals away from home and follow a less stringent eating schedule. Total dietary methods such as food records, 24-hour recall, food frequency questionnaire, and targeted diet and/or behaviours methods have advantages and disadvantages (Table I).

6. Body composition assessment in children and young adolescents

BMI is commonly used in clinical practice to represent adiposity status (normal, overweight, and obese) (30). BMI, formulated from weight and height, is an inexpensive and convenient indicator of body fat mass for most children and shows the relative position of the child's BMI among children of the same gender and age. BMI in children is often reported as a percentile ranking and subsequent weight status category. BMI is plotted on the CDC BMI-for-age gender-specific growth charts and is used to assess the size and growth patterns of children aged ≥2 years in the United States (31).

The relationship between BMI and adiposity was demonstrated in a study on Italian children with a wide range in age (32). Although a strong positive relationship was found between BMI and total body fat, BMI compared across different age groups can be erroneous and results must be evaluated cautiously. Total body fat was shown to increase with age while the percentage of body fat decreased with age. The association between childhood BMI and adult adiposity has been supported in some studies but refuted in other studies (33). A large longitudinal study aimed to compare the accuracy of childhood levels of BMI and triceps skin-fold thickness in predicting adult adiposity. The study found that childhood BMI-for-age was significantly associated with adult levels of BMI. This correlation was stronger among girlsand among older children (9-17 years). Adult obesity and excessive body fat mass consistently increased as childhood BMI-for-age increased, even among young children.

7. Conclusions

In conclusion, it is clear from the above citations that proper knowledge of dietary options is necessary to secure the future of young adolescents from the consequences of obesity.

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