Feature Article

Animal source foods for the alleviation of double burden of malnutrition in countries undergoing nutrition transition

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Implications

- Double burden of undernutrition in children and adults along with high prevalence of obesity-related chronic diseases in adults in developing countries undergoing nutrition transition is an enormous policy challenge.
- Interventions that promote childhood growth and help maintenance of muscle mass in later life would be the key to tackle the double burden of malnutrition.
- Animal source foods could have an important role in combating the double burden of malnutrition in low-income countries where diets are predominantly cereal based with very low intakes of animal source foods.
- In the settings where childhood undernutrition is highly prevalent, affordable animal source foods should be explicitly promoted as a part of guidelines on infant and young child feeding.
- Nutrition counseling needs to be coupled with enhancing the affordability and access to animal source foods for low-income households through macro- and micro-level policy interventions.

Keywords: animal source foods, body composition, double burden of malnutrition, muscle mass, nutrition transition

Introduction

The double burden of undernutrition and obesity-related chronic diseases in countries undergoing nutrition transition is a significant impediment to sustainable development. For instance, recent reports from the ICMR-INDIAB study in India showed that almost one in four urban adults over 55 yr of age were diabetic (Anjana et al., 2017). This is coupled with a steep rise in the proportion of overweight and obese adults in the last decade (from 10% in 2005 to 2006 to 20% in 2015 to 2016) as per the third and fourth rounds of the National Family Health Surveys. Rapidly burgeoning chronic disease burden coexists with high burden of undernutrition in adults and children, as indicated by almost 20% prevalence of chronic energy deficiency (body mass index [BMI] less than 18.5 kg/m^2) in adults and around 38% prevalence of stunting in children under 5 yr of age, which represents an enormous policy challenge.

There has been increasing recognition that tackling this complex challenge needs “double-duty” actions in terms of policies and interventions that have the ability to simultaneously reduce the undernutrition and overweight/obesity; the two seemingly contrasting forms of malnutrition (Hawkes et al., 2017). Identifying the “shared drivers” between different forms of malnutrition and then targeting interventions to these shared drivers would help reduce all forms of malnutrition. Understanding childhood undernutrition and adult overnutrition as a continuum rather than mutually exclusive problems is particularly useful in this regard.

A substantial body of evidence suggests that body composition with low muscle mass throughout life may be an important link to explain the coexistence of high prevalence of childhood undernutrition and adult-onset chronic diseases in countries undergoing nutrition and epidemiological transition. A number of studies from India and other Asian countries have shown increased cardiometabolic risk within a normal (less than 18.5 to 25 kg/m^2) BMI range (Vikram et al., 2003), which has been mainly attributed to the peculiar body composition with high fat and low muscle mass in Asians compared with the other ethnic groups (Misra et al., 2015). Another line of evidence based on a large number of studies has demonstrated that lower birth weight and growth faltering during infancy programs the body toward a lower lean body mass and muscle mass in adulthood (Kulkarni et al., 2014). Childhood undernutrition thus coexists with adipose body composition in adults, especially in South Asian countries. On this background of chronic muscle mass deficit, increasingly obesogenic environment linked with nutrition transition, particularly the excessive intake of processed foods and reduced energy expenditure, results

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in fat accretion with elevated risk of obesity and metabolic syndrome.

Low muscle mass increases the risk of fat accretion and insulin resistance in multiple ways. The skeletal muscle is a major site for glucose disposal at rest, and reduced skeletal muscle mass and function is associated with decreased insulin sensitivity. Moreover, the low muscle mass itself may predispose to fat accretion due to its significant effect on energy balance as the synthesis and breakdown of muscle protein are largely responsible for the energy expenditure of resting muscle. Wolfe (2006) estimated that an approximate 10-kg deficit in muscle mass translates to conservation of ≈100 kcal/d in energy expenditure, which in turn may result in accumulation of 4.7-kg fat mass in a year. In addition, a number of energy-sparing mechanisms may take place in nutritionally stunted children who have low muscle mass including impaired fat oxidation and preferential oxidation of carbohydrate (Martins et al., 2011). As oxidation of 1 g of carbohydrate is equivalent to 4 kcal compared with 9 kcal with the oxidation of 1 g of fat, the tendency to store fat is enhanced with this adaptation, especially in an environment where physical activity is low.

Dietary intake of important nutrients such as high-quality protein, essential fatty acids, and micronutrients including iron, zinc, vitamin A, and calcium influence the intrauterine and childhood growth. These nutrients are also important for the development and maintenance of adult lean body mass and muscle mass. Suboptimal diets lacking these important nutrients, therefore, could be the main reason underlying the double burden of childhood undernutrition and adiposity during adulthood. Focusing on food systems to enhance availability and access to diverse diets rich in the above nutrients would address the "shared drivers" of the double burden of undernutrition and overnutrition.

Role of Animal Source Foods

In resource-poor settings of the developing countries, higher proportion of dietary energy is consumed as low-cost cereals (e.g., rice, maize, wheat, sorghum) or root crops such as cassava (Figure 1). The proportion of energy provided by animal source foods typically varies from 5% to 10% in low-income countries compared with >30% in industrialized countries. Animal source foods, being rich source of high-quality protein, essential fatty acids, and highly bioavailable micronutrients including zinc, iron, calcium, vitamin A, and B12 could contribute substantially to reducing childhood undernutrition and optimal development and maintenance of muscle mass throughout life, thereby reducing the double burden of malnutrition.

In the following sections, we provide a brief appraisal of evidence on the relationship of animal source foods intake with 1) stunting and muscle mass in children and 2) lean body mass and muscle mass in adults particularly focusing on studies conducted in developing countries. Because a comprehensive review of this evidence is beyond the scope of this article, this review is illustrative rather than exhaustive. It is also important to note that the discussion in following sections is largely relevant in the context of developing countries such as India, where the diets are predominantly cereal based with very low intake of animal source foods (Figure 2).

Animal Source Food Intake and Child Nutrition

A number of observational and intervention studies have demonstrated the beneficial effects of including animal source foods in children's diets for improving linear growth as well as micronutrient status.

Observational studies

Many observational studies in infants and children which examined the relationship between animal source foods intake and childhood nutrition, especially linear growth, have shown a strong association of higher animal source foods

Figure 1. A high proportion of dietary energy is consumed as low-cost cereals (e.g., rice, maize, wheat, sorghum) or root crops such as cassava in the resource-poor settings of the developing countries.

Figure 2. In developing countries such as India, diets are predominantly cereal based with very low intake of animal source foods. It is important to bear this in mind when evaluating the practicality of animal source foods.

consumption with reduced stunting as well as wasting. For example, a cross-sectional study in 3,150 infants and toddlers from Democratic Republic of Congo, Zambia, Guatemala, and Pakistan showed that consumption of meat and fish was associated with reduced likelihood of stunting as well as wasting after controlling for relevant confounders (Krebs et al., 2011). Another independent household survey in more than 2,500 Indian children showed that the odds of severe stunting were 60% higher in children of mothers who did not consume milk or dairy products at least once weekly during pregnancy, whereas low consumption of eggs was associated with a twofold increase in the odds of stunting in children (Aguayo et al., 2016). Similarly, the SEANUTS study, which examined the associations between dairy consumption and nutritional status in more than 12,000 children from Indonesia, Malaysia, Thailand, and Vietnam, found that the prevalence of stunting was almost double in nondairy consuming children compared with those who consumed dairy on a daily basis (21.4% vs. 10%; Nguyen Bao et al., 2018). In addition, a review based on data on 74,548 children (6 to 23 mo old) from 39 countries showed that children whose diet did not include any animal source foods had 1.44 higher odds of being stunted compared with children who consumed all three types of animal source foods—meat, egg, and dairy (Krasevec et al., 2017).

Intervention studies

The findings of the observational studies are in line with the intervention studies although only a few high-quality randomized controlled trials evaluating the impact of animal source foods supplementation on growth and body composition of children have been reported. Most of these studies were conducted in African countries, with scarce information available from Asian countries. For example, a randomized controlled trial from Ecuador in children aged 6 to 9 mo demonstrated that egg supplementation (one per day) for 6 mo reduced prevalence of stunting by 47% and underweight by 74% compared with children in the control arm who received no intervention (Iannotti et al., 2017). Another study from rural Uganda assessed the impact of egg supplementation on growth of primary school children (6 to 9 yr) attending a school feeding program (5 d/wk for 6 mo). The researchers found that children receiving 2 eggs/d had a greater increase in height and weight compared with those who received either 1 egg/d or no eggs. Moreover, participants receiving either one or two eggs per day had a significantly higher increase in mid-upper-arm circumference, indicating large gain in muscle mass, compared with those not receiving eggs (Baum et al., 2017). Similar findings were observed in a study from Kenya which examined the growth and muscle mass of 6- to 14-y-old schoolchildren from two cohorts with over 900 children after supplementation with meat, milk, or energy for two academic years compared with a control group without a supplement (Neumann et al., 2013). The results showed that children in the meat group had significantly higher gain in mid-upper-arm muscle area than the other groups. To a lesser extent, children who received the milk or energy supplement also gained more mid-upper-arm muscle area than the controls. Importantly, of all groups, the meat group showed the least increase in mid-upper-arm fat area alleviating the concerns about increased adiposity. A systematic review which assessed the impact of supplementing usual diet with dairy products on physical growth estimated benefit of approximately 0.4 cm per annum additional growth per 245 mL of milk consumed daily (de Beer 2012). However, the majority of studies included in this systematic review were conducted in developed countries as very few efficacy trials of dairy supplementation for growth improvement in infants or young children have been reported from developing countries.

A few studies, on the other hand, do not support the above evidence. For instance, a large cluster randomized efficacy trial conducted in Democratic Republic of Congo, Zambia, Guatemala, and Pakistan with over 1,000 subjects comparing the daily provision of 30 to 45 g of lyophilized beef with micronutrient fortified rice-soy cereal product from 6 to 18 mo of age did not find a positive impact for either intervention to prevent progressive linear growth faltering in these settings with high baseline rates of stunting (Krebs et al., 2012). Another recent meta-analysis which assessed the effectiveness of animal source foods compared with other feeding interventions or no intervention regarding improving growth and developmental outcomes in children reported uncertainty regarding the beneficial effects of the animal source foods supplementation due to low quality of the evidence (Eaton et al., 2019).

Given the high nutrient density of animal source foods, promotion of livestock production is considered as a strategy to enhance diet quality and improve child nutrition. The empirical evidence to support the impact of these interventions is, however, limited. For example, by evaluating the impact of Heifer International's dairy cow and meat goat donation programs in Rwanda, Rawlins et al. (2014) reported that, in households that received pregnant cows, height-for-age *z*-scores of children under the age of five increased by about 0.5 standard deviations. Similarly, using data from rural Bangladesh, Choudhury and Headey showed that household dairy production was associated with 0.52 standard deviation increase in height-for-age *z*-scores in the critical 6- to 23-mo growth window. These findings have been corroborated by studies from Uganda (Fierstein et al., 2017) and eastern Africa (Mosites et al., 2017). A community-based dietary diversification intervention, which promoted animal source foods (especially soft-boned fish), showed enhanced *z*-scores, mid-upper-arm circumference and arm muscle area in 30- to 90-mo-old children in Malawi although there was no significant impact on weight or height gain (Gibson et al., 2003).

Animal Source Foods Intake and Body Composition in Adults

Apart from its beneficial role on linear growth and muscle mass development during childhood, animal source foods intake continues to exert positive influence on muscle mass throughout life due to the anabolic properties of dietary proteins. Plant proteins have lower digestibility and are deficient in essential amino acids leucine, lysine, and methionine. Current evidence suggests that animal source foods proteins may be more anabolic than plant proteins as muscle protein synthesis requires availability of a complete amino acid profile (van Vliet et al., 2015). The majority of the studies exploring the role of animal source foods in muscle mass and function have been done with dairy products as both whey and casein proteins contain high amount of branched-chain amino acids and stimulate muscle protein synthesis. Whey protein, due to its rapid digestion and amino acid absorption kinetics, has been shown to stimulate muscle protein synthesis to a greater extent compared with casein in young adults and in older men (van Vliet et al., 2015).

Cross-sectional studies have shown that total protein and animal protein intake, but not plant protein intake, are positively associated with muscle mass index and leg lean mass (Skau et al., 2015). In addition, longitudinal studies have shown that higher intakes of total protein and animal protein are associated with a reduced loss of lean mass over 3 yr of follow-up (Isanejad et al., 2015).

Impact of Animal Source Foods on Body Composition: Underlying Mechanisms

The positive impact of animal source foods on childhood growth and adult muscle mass seen in observational and intervention studies could be linked with multiple mechanisms as summarized in Figure 3. Optimal body composition depends on age appropriate bone and muscle growth in childhood and adolescence, and maintenance of muscle mass in later life. The positive impact of animal source foods on body composition is mediated by key signaling mechanisms affecting linear growth and muscle synthesis as well as by the impact of dietary proteins on the satiety, thereby influencing calorie intakes.

Although animal source foods, in general, are a rich source of bioavailable micronutrients, their superior protein density and quality stands out in comparison to plant proteins. It is well known that essential amino acid content and digestibility of animal source food proteins is far superior to that of plant proteins. Recent studies using stable isotopic methods have shown that quality of protein as determined by availability of indispensable amino acids is quite lower (20% to 30% for lysine and leucine) for legumes compared with eggs or meat (Devi et al., 2018; Kashyap et al., 2018). It is well known that protein intake induces an increase in serum IGF1 levels, and restriction of dietary proteins leads to its reduction via increased clearance (Bonjour et al., 1997). Studies have shown that the positive impact of milk consumption on child growth may be mediated through higher serum IGF1 levels among children (Hoppe et al., 2004). Furthermore, supplementation of essential amino acids also increased serum IGF1 levels and protein synthesis in human participants suggesting that the quality of protein is critical in achieving desired body composition changes (Dillon et al., 2009). A metabolomic study among 12- to 59-mo-old children demonstrated a decline in serum essential amino acid

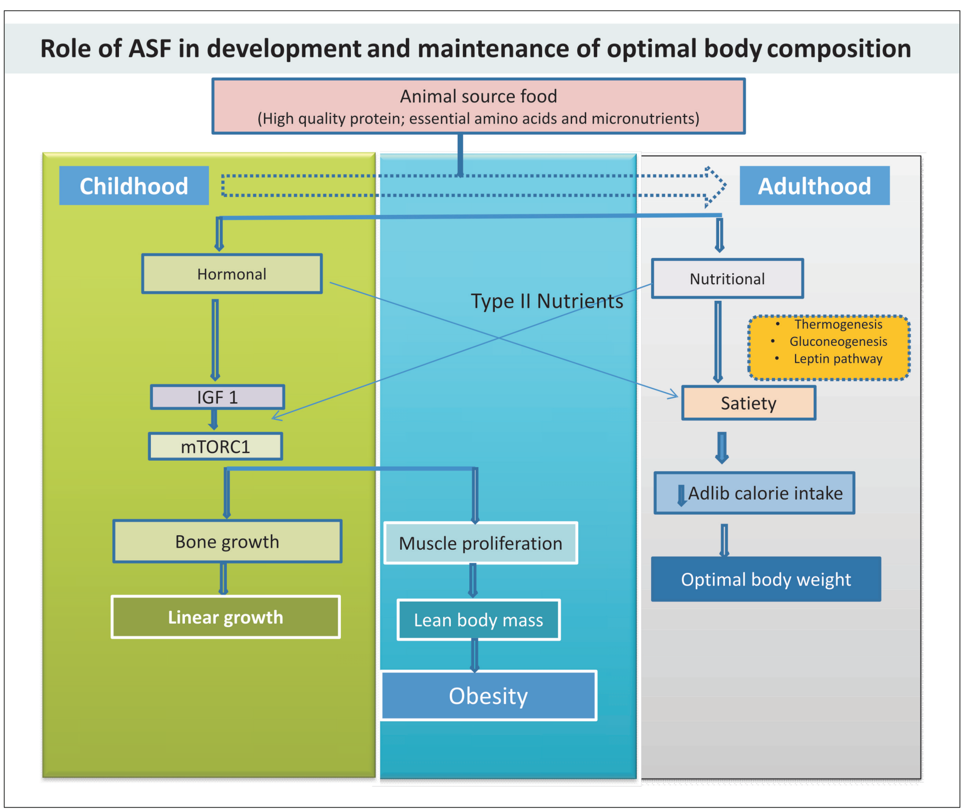

Figure 3. Role of animal source foods in development and maintenance of optimal body composition.

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levels in stunted children, of which leucine showed the strongest association with growth (Semba et al., 2016). Thus, the positive association of animal source foods intake with growth could be, at least in part, due to higher protein quality.

Linear growth is regulated by complex interweaved genetic and hormone-mediated cell signaling mechanisms, which are nutrition sensitive. Physiologically, nutrients are divided into types 1 and 2. The deficiency of type 1 nutrients such as iron and B-vitamins manifests in biochemical changes without affecting the linear growth, whereas the deficiency of type 2 nutrients (such as protein, zinc, magnesium, phosphorus, and potassium) manifests in growth faltering with no change observed in blood levels (King, 2011). The beneficial effect of animal source foods on linear growth in childhood could also be due to the higher density and bioavailability of type 2 nutrients such as zinc and protein in animal source foods compared with plant foods as independent studies have shown the positive impact of supplementation of these nutrients on lean mass (Seino et al., 2018).

In mammals, the mechanistic target of rapamycin (mTOR) appears to be the master regulator of anabolic reactions. Interestingly, the hormonal (growth factors), metabolic (energy and oxygen), and nutritional factors (essential amino acids, i.e., leucine, lysine, etc.) appear to converge in regulating the mTOR pathway (Laplante et al., 2012). The essential amino acids leucine and arginine not only stimulate the activity of the mTOR pathway, but also are absolutely required for growth factor-induced mTOR activation. In fact, emerging evidence suggests that leucine supplementation along with dietary protein improves the muscle mass, reduces weight gain, and improves protein synthesis in animal models and humans (Churchward-Venne et al., 2014).

Higher protein intake also appears to help in weight management in overweight individuals because replacing other macronutrients with high-quality proteins has been shown to reduce body weight. Studies have shown that increasing the protein intake from 15% to 30% by reducing equivalent amount of fat resulted in sustained reduction in appetite, ad libitum calorie intake and reduced body weight among healthy adults (Weigle et al., 2005). Indeed, in a study among overweight/obese subjects fed an isocaloric diet, egg protein showed greater satiety compared with cereal protein (Bayham et al., 2014). Last, multiple observational and intervention studies have shown that animal source foods consumption also help reduce age-related muscle loss, possibly by stimulating muscle tissue synthesis (Isanejad et al., 2015). Although the mechanism of reduced appetite during high protein intake appears to be complex, possible mechanisms include increased thermogenesis, gluconeogenesis in the liver, and secretion of anorexigenic or orexigenic neuropeptides via modulating the leptin sensitivity in the central nervous system (Weigle et al., 2005; Veldhorst et al., 2008). Furthermore, an inverse relationship between serum amino acids and appetite has also been reported (Mellinkoff et al., 1956). The increase in the serum amino acid concentration following oral or parenteral supplementation resulted in decreased appetite and a corresponding decline in serum amino acids restored the appetite, implying that the effect was specific to amino acids. Therefore, it appears that beneficial effects of animal source foods on body composition are largely mediated by protein quality and essential amino acid content.

Summary

The double burden of undernutrition and overnutrition in transitioning societies represents an enormous challenge to tackle the two seemingly contrasting forms of malnutrition. Interventions to reduce childhood as well as adult undernutrition through food supplementation programs might simply aggravate another problem of increasing obesity if the food supplements are not well balanced in terms of protein quality. Dealing with the complex problem of the double burden of malnutrition requires actions that have the potential to reduce undernutrition without producing a substantial increase in obesity. Improving childhood growth and maintenance of optimal body composition with higher muscle mass later in life seems to be the key to addressing the double burden of malnutrition. As shown by a large body of evidence, animal source foods have an important role in this context due to their effect of promoting childhood growth and maintaining optimal muscle mass in later life.

In the settings where childhood undernutrition is highly prevalent, affordable animal source foods should, therefore, be explicitly promoted as a part of guidelines for infant and young child feeding. But for the nutrition counseling interventions to be effective, these efforts need to be coupled with enhancing the affordability and access to animal source foods for low-income households through macro- and micro-level policy interventions. Finally, it is important to consider that promoting increased production and intake of animal source foods creates another challenge in terms of increased environmental costs. It is, therefore, necessary to carefully balance improved nutrient density of diets with sustainable strategies of livestock production.

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