Review

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Enhancing the microbiome in the maternal-infant dyad: Perspectives from maternal and infant nutrition

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ABSTRACT

Establishing the microbiome is an important milestone for infant health. The type of delivery, gestational age, antibiotic use, and infant feeding practices significantly impact this process. However, interest in the effects of maternal diet and nutrition has grown.

The objective of this review is to present an update on the microbiota in the mother-child dyad and the role of maternal nutritional status and diet in its modulation. Scientific articles in electronic databases were reviewed.

Adherence to established dietary guidelines during pregnancy and lactation, as well as other recommendations based on the study of foods that are sources of fiber, unsaturated fatty acids, and fermented foods, is a good starting point for promoting a healthy microbiome from the early years of life.

Keywords: *gastrointestinal microbiota; healthy diet; human milk; infant health; women's health.*

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INTRODUCTION

The first thousand days of life have been recognized as a critical period for programming an individual's health.[1] The study of the human microbiome, understood as the set of microorganisms, their genes, and metabolites, has reaffirmed the role of this period in metabolic and immunological health. The initial colonization and its maturation process promote the integrity of the epithelial barrier, the development and maturation of the enteric immune system, and both innate and adaptive immunity.[2,3] Therefore, the establishment of the microbiome has been postulated as a key milestone in the prevention and treatment of various intestinal and systemic health conditions.

Around 50% of the microbiota of newborns comes from different maternal niches, with human milk being the predominant source, providing nutritive and non-nutritive compounds that promote the growth and maintenance of the infant microbiota.[4] Given the factors that modulate the microbiota of newborns, it is clear that the mode of delivery, gestational age, use of antibiotics, feeding practices such as breastfeeding or the use of formula, and the introduction of complementary foods all affect the establishment of the microbiome.[1,5]

Scientific evidence demonstrates the impact of malnutrition in lactating women on child health and nutrition.[6,7] However, priority continues to be given to health and nutrition support for pregnant women, newborns, and breastfeeding, overlooking women in the lactation stage, in which energy and nutritional needs are increased, and low intake of some nutrients and food-derived compounds conditions transfer through breast milk.[8,9] In addition to the contribution of nutrients, the transmission of bacteria, short-chain fatty acids, and prebiotics such as oligosaccharides must be considered. It is estimated that about 25% to 30% of the microbiota comes from human milk, which can harbor more than 800 different bacterial species necessary for the assembly of the infant's microbial ecosystem.[10,11]

Recent evidence demonstrates the role of food in balancing the microbiota, an important consideration for breastfeeding women, given the transfer of microorganisms to the newborn. Therefore, the objective of this article is to provide an update on the microbiota in the mother-child dyad and the roles of nutritional status and maternal diet in modulating it.

METHODS

Scientific articles were reviewed in the electronic databases PubMed, ScienceDirect, and Google Scholar. To ensure a search focused on the impact and/or relationship of maternal diet and nutrition on the maternal microbiota, human milk, and the infant's gut microbiota, we used the following keywords: "Maternal Nutrition", "Dietary Intake", "Nutrition Status", "Body Weight", "Human Milk", "Infant", and "Microbiome". These words were selected to cover the important aspects of the proposed thematic development.

INTESTINAL MICROBIOTA IN THE MOTHER-INFANT DYAD

During pregnancy, various physiological, endocrine, metabolic, and intestinal microbiota adaptations occur. During pregnancy, a change in a woman's microbiota has been observed, which is related to the diabetogenic phenotype characteristic of this period.[12] During the first trimester, the gut microbiota is comparable to that of healthy non-pregnant women; however, its composition changes significantly in the second and third trimesters.[13]

Starting in the second trimester, there is an increase in Proteobacteria and Bifidobacteria and a reduction in the amount of butyrate-producing bacteria. In general, the gut microbiota during pregnancy is characterized by low alpha diversity (intra-individual bacterial diversity) and high beta diversity (inter-individual bacterial diversity); the most notable changes occur in the third trimester.[14,15] At the end of pregnancy, the abundance of certain bacteria, such as bifidobacteria, increases, which is related to hormonal adaptations, including increased progesterone and changes in adiposity.[16,17]

In the postpartum period, the predominant phylum is usually Firmicutes, and the most abundant genus has been observed to be *Bacteroides* spp.[18,19] However, the adaptations of the female microbiota during lactation are unclear, which could be conditioned by physiological, metabolic, and hormonal changes, as well as food consumption.

In infants, the establishment of microbiota is gradual and characterized by three stages: development, transition, and stability. At the beginning, the microbiota has low alpha diversity and high beta diversity. It is dominated by aerotolerant microorganisms that can reduce oxygen levels in the infant's intestine, creating an optimal environment for the subsequent growth of anaerobic bacteria, such as bifidobacteria.[20] In the second semester the introduction of complementary foods enriches the intestinal microbiota, with an increase in the abundance of Bacteroidetes and butyrate-producing bacteria such as *Faecalibacterium* spp.[21,22] At three years of age, an increase in the phylum Firmicutes and a decrease in the phylum Actinobacteria are observed, at which point the microbiota is similar to that of adults and begins to reach homeostasis (*Figure 1*).[23]

During early life, the microbiota is highly dynamic and susceptible to environmental influences. Factors such as human milk supply, antibiotic use, feeding patterns, and lifestyle, contribute to its modulation. However, the first colonizers have a significant impact on adult microbiota; the genus *Bifidobacterium* spp. is one of the best markers of gut microbiota health in childhood.[24]

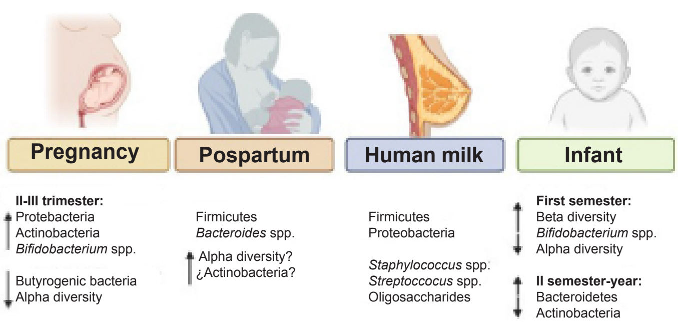
As mentioned above, human milk is an important source of microorganisms for the infant's microbiota. When a child is breastfed, they consume approximately 800 ml of milk/day, with an average of 10^7 CFU/ml of bacteria. The dominant phyla in human milk are usually Firmicutes and Proteobacteria, and the genera *Staphylococcus* spp. and *Streptococcus* spp. are common.[25] Various transfer routes have been described that explain the origin of these microorganisms in the mammary gland: retrograde translocation of bacteria from the infant's oral cavity, the mother's skin, oro-mammary pathway, and the entero-mammary pathway. The latter allows us to understand how some bacteria present in the maternal intestine migrate to the mammary gland during late pregnancy and postpartum in a process mediated by dendritic cells, CD18+ cells, and macrophages, which cross the epithelium and reach the mesenteric lymph nodes, actively traveling through the mucosa-associated lymphoid system.[26,27]

This process is linked to changes in the digestive system that occur during pregnancy, such as increased intestinal permeability and decreased peristalsis.[28] Thus, the intestinal and hormonal adaptations of pregnancy contribute to changes in the mother's microbiota that favor the translocation of bacteria during the postpartum period, making digestive health and the maternal microbiota key factors in the bacteria to be transferred.

THE ROLE OF NUTRITIONAL STATUS AND MATERNAL DIET IN THE MATERNAL-INFANT MICROBIOTA

Maternal overweight has been shown to affect the alpha diversity of the microbiota in human milk and reduce the abundance of *Bifidobacterium* spp. in the mother-infant dyad.[29,30] It should be noted that maternal overweight and excessive gestational weight gain increase the incidence of cesarean delivery,[31] which, in turn, could affect the establishment of breastfeeding by delaying lactogenesis II,[32] which interrupts the transfer of beneficial microorganisms through the birth canal and human milk. This could be a mechanism associated with the early onset of obesity, in which a reduction in bifidobacteria has been observed, specifically in children who become overweight.[33] Although the available studies present more evidence in relation to maternal overweight, maternal undernutrition is a condition that continues to be present in low- and middle-

Figure 1. Microbiota in the mother-child dyad



Source: own elaboration with Biorender.com income countries. Srugo *et al*.[34] demonstrated in an animal model that undernutrition during pregnancy disrupts the mother's intestinal homeostasis, promoting an inflammatory state that compromises the intestinal barrier and delays fetal intestinal development.

Variations in maternal-infant microbiota have been identified in relation to macronutrient consumption. A high-fat maternal diet during pregnancy is associated with a lower abundance of *Bacteroides* spp. in the newborn's microbiota, while the recommended fat intake together with a high fiber intake is associated with increased richness and lower abundance of *Bacteroidaceae* in the maternal gut microbiota during pregnancy.[35] Xi *et al*.[36] identified a relationship between the mother's dietary intake and the content of long-chain fatty acids in breast milk, which was associated with the presence of healthy microbial species such as *Lactobacillus* spp. in the infant's gut microbiota. Padilha *et al*.[37] found that postpartum intake of polyunsaturated fatty acids was positively associated with the abundance of *Bifidobacterium* spp. in milk. At the same time, LeMay-Nedjelski *et al*.[38] reported that trans-fat intake was positively associated with *Staphylococcus* spp. and *Gemella* spp. in the milk of women with varying degrees of gestational glucose intolerance.

Fiber consumption is one of the compounds with the greatest positive impact on the microbiota of breast milk and infants.[35] It has been linked to a greater abundance of *Lactobacillus* spp. and *Bifidobacterium* spp., and a lower abundance of *Enterobacter* spp. in breast milk.[39]

Protein consumption has been less widely described. Cortes-Macías *et al*.,[40] in a sample of 120 women from the MAMI cohort (The Power of Maternal Microbes on Infant Health) cohort in the Spanish Mediterranean area, conducted an analysis in which they grouped women according to their dietary intake: the first group was characterized by the consumption of vegetable proteins, fiber, and carbohydrates, while animal proteins and lipids characterized the second. In contrast to the relevant findings, they found that the milk of mothers in group one had a greater relative abundance of genera *Staphylococcus* spp., *Lactobacillus* spp., and *Bifidobacterium* spp., the latter considered beneficial taxa for infants; while the milk of mothers in group two was characterized by genera *Bacteroides* spp. and *Escherichia* spp., which are more associated with early maturation of the microbiome, in which fewer bifidobacteria are observed.[24]

Micronutrition, through the intake of vitamins and minerals, is a factor that influences the mother and infant health. Regarding microbiota, associations have been observed, especially with the intake of fat-soluble and B-complex vitamins; however, the results are diverse and do not show a clear trend.[35,41]

Regarding the consumption of specific foods, fermented foods have gained interest. Costa de Almeida *et al*.[42] in a murine model observed that consuming kefir during lactation promotes the abundance of butyrogenic bacteria in the intestinal microbiota of offspring. Along the same lines, Bizanz *et al*.,[43] when providing yogurt supplemented with *Lactobacillus rhamnosus* GR1 and moringa to women during pregnancy and the first month postpartum, observed an increase in *Bifidobacterium* spp. in the newborn microbiota. These results are consistent with the benefits of dairy consumption in this population.

In contrast, ultra-processed products have been linked to health problems for both mother and child,[44] as they alter the gut microbiota due to their saturated fat, trans fat, sugar, and additive content.[45] Findings from Latin American studies show, on the one hand, the relationship between maternal sugar intake and lower abundance of *Bifidobacterium* spp. in breast milk,[39] and, on the other hand, alterations in the infant gut microbiota in children who are not breastfed during their first year of life and consume these types of products.[46]

PERSPECTIVES ON NUTRITION FOR THE CARE OF THE MATERNAL-INFANT MICROBIOTA

Currently, the study of the human microbiome is opening new perspectives for promoting health and preventing disease during the first thousand days of life, period during which the microbiota is unstable and highly dynamic. For this reason, it is imperative to safeguard food safety, consumption patterns, and the nutritional status of women during pregnancy and breastfeeding. The adherence to established dietary guidelines for this population group and other recommendations based on food studies[47] is a good starting point for promoting a healthy microbiome from the first years of life.

Fiber intake should ideally be above 30 grams/day,[48] which promotes intestinal eubiosis in women, dominated by species that produce short-chain fatty acids and lactic acid.

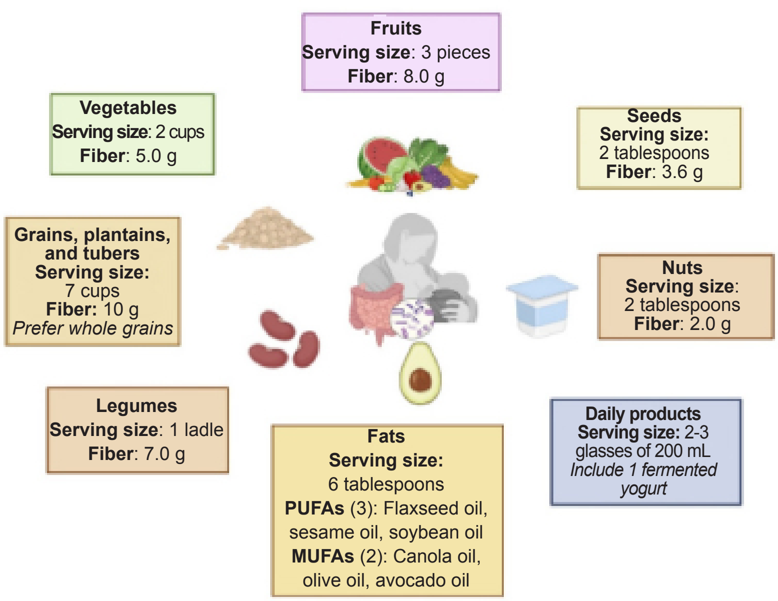
To achieve this reference intake, it is recommended to consume legumes (beans, lentils, chickpeas), whole grains (whole wheat, rye, barley, oats), whole fruits and vegetables, and complex carbohydrates such as brown rice, potatoes with skin, cassava, and plantains (*Figure 2*).

The consumption of foods high in fat—which can affect the maternal and neonatal microbiome—should be avoided,[35] and an optimal distribution of fatty acids should be promoted. To this end, it is important to guide women in the proper selection and use of oils in food preparation, favoring olive, canola, and soybean oils,[49] as well as the daily inclusion of oilseeds such as peanuts, almonds, pistachios, walnuts, and pumpkin seeds, due to their contribution of fatty acids, phytosterols, and fiber. Consuming omega-3-rich fish such as salmon, mackerel, sardines, and herring, as well as alternative sources (flaxseed and chia oil and seeds, sacha inchi oil, and canola oil), is also recommended. However, when fish does not come from a safe source due to its high heavy metal content, supplementation with 300 mg per day of docosahexaenoic acid (DHA) plus eicosapentaenoic acid (EPA) is recommended, of which at least 200 mg should be DHA.[50]

Animal proteins (meat, dairy products, and eggs) are of high biological value, which enhances their bioavailability. It is therefore recommended that they be included in the mother's diet daily in a balanced manner, as excess consumption could affect the abundance of Actinobacteria and increase the abundance of *Streptococcus* spp. in breast milk.[6] Regular consumption of legumes provides a rich source of plant-based protein and dietary fiber and may help meet the increased protein requirements which have been estimated at approximately 1.5-1.8 g/kg body weight.

Consuming fermented foods is recommended daily due to their beneficial effects on maternal and child health. However, it is important to guide mothers in selecting safe sources produced under quality conditions and free of alcohol and pathogens; yogurt, kumis, and kefir are good options. Additionally, it is recommended to encourage women to consume a variety of foods, especially fruits and vegetables of different colors, the latter with adequate processing and cooking to enhance the bioavailability of bioactive compounds such as polyphenols found in grapes, blueberries, strawberries, and raspberries, and sulfur compounds abundant in cruciferous vegetables such as broccoli, cauliflower, cabbage, and radishes.

Figure 2. Food planning at the meeting of maternal dietary fiber recommendations



PUFAs: polyunsaturated fatty acids; MUFAs: monounsaturated fatty acids. Fiber content is expressed as grams per serving.
Source: own elaboration with Biorender.com

Advances in maternal and child nutrition, supported by interdisciplinary research spanning basic and applied sciences, are expected to contribute to the development of personalized nutrition strategies grounded in increasingly precise dietary recommendations aimed at optimizing microbiome health from early life. ■

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