Microbiome, Breastfeeding and Public Health Policy in the United States: The Case for Dietary Fiber

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ABSTRACT: An emerging body of literature has highlighted the significance of breastmilk oligosaccharides and dietary fibers in complementary weaning foods for the development of the infant's microbiome that has both short- and long-term health implications. This review highlights the newborns' consumption of fiber and oligosaccharides as directly linked to the mother's diet, and that current dietary recommendations for pregnant mothers in the United States and globally fall short in both addressing the importance of dietary fiber intake for enhancing mother's health and establishing the developing infant microbiome. Although limited in data, there is suggestion for maternal dietary interventions to include healthy fibers as an effective means of promoting infant health via modification of breast milk composition. This paper argues that there is an urgent need for a two-fold national policy that addresses the significance of fiber in breastfeeding mothers' diets and modifies the dietary recommendations accordingly, and provides a paid parental leave, which would enable mothers to not only breastfeed for at least six months, but to also effectively follow the dietary recommendations needed to support breast milk quality that is linked to their infants' health.

KEYWORDS: Microbiome, breastfeeding, public policy, dietary fiber, health policy

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Introduction

An emerging body of research on the microbiome has already revolutionized disciplines ranging from environmental microbiology to medicine, and could also have implications for public health policy. Public health implications of microbiome research are not clear-cut, however: as researchers actively investigate what constitutes a "healthy microbiome," it is difficult to craft policies based on existing knowledge of microbiome functions for improving human health.[1,2] Indeed, in most cases, research findings are descriptive associations between certain diseases and microbiota composition. Although we gain new insights every day, causal relationships among variables are not fully and widely established. As D'Hondt et al[3] puts it,

> The causal relations of nutrition, gut microbiome composition and health is not clearly understood yet, such as whether a healthy microbiome can be defined at population level, what determines its resilience when disturbed, or how its composition can be beneficially manipulated.

Furthermore, microbiomes exhibit extensive individual variation within households and across the globe.[4-8] In addition, microbial interactions are largely unknown and the question as to whether or not some bacteria are harmful seems to be context-dependent, adding further challenges to policy-making.[9-11] Thus, public policy's three common prerequisites, namely, generalizability, efficacy and safety are not easily met when it comes to translating the findings of the microbiome research into public policy.[12]

Not all research findings fail to meet the criteria, however. The significance of oligosaccharides as constituents in breastmilk is a case in point. It has been long known that breastfeeding sets the foundation for a healthy baby with short- and long-term health implications.[13,14] Recent research findings further shed light on *how* and *why* the oligosaccharide components in breastmilk are crucial. It is well established that breastmilk is essential in establishing the microbiome for babies, setting the foundations for healthy growth and development.[15,16] Failing to establish those foundations, as recent research has suggested, will have significant health implications for future generations. Therefore, establishing new public policies that address these key findings around the intake of dietary fiber across one's lifespan, and particularly during pregnancy and lactation is critical for preventing diseases and thereby avoiding expensive curative care later on.

A closely related policy area is the lack of a paid maternity leave policy in the United States. Empirical evidence has demonstrated that women are more likely to initiate and maintain breastfeeding if they are able to delay their return to work after giving birth.[17] In the absence of paid maternity leave, women either stop working entirely, which significantly reduces the family's income, or they go back to work too early, which makes breastfeeding unlikely. Neither option is ideal for the health of the babies or their mothers. Although there are many factors that affect mothers' decision to breastfeed, public policy concerning parental leave is a crucial one. It is no coincidence that in countries such as Sweden and Norway, where mothers as well as fathers enjoy generous leaves after birth of a child without worrying about their paychecks, are also the countries where breastfeeding ratios are the highest. This close relationship between breastfeeding and paid parental leave necessitates a discussion of these policies together.

This paper has two objectives. First, it reviews the growing body of literature that demonstrates the significance of fiber and prebiotics for the gut microbiome and why it is important for infants to receive oligosaccharides as well as bacteria and other nutrients through breastmilk. These components of the milk help develop and establish infants' maturing microbiome. Second, the paper evaluates the existing dietary recommendations for breastfeeding mothers in the United States in comparison to other developed countries. By discussing the United States as a case study, this paper argues for an urgent need to modify the existing dietary recommendations for lactating mothers. The need for dietary modification goes beyond the United States, as there is a global pattern in the lack of emphasis on daily fiber intake and how that negatively impacts gut health.

Related to this objective, the paper also advocates for a national, paid parental leave to promote healthy breastfeeding and dietary habits of lactating mothers. The United States represents a unique case in this regard because it is currently the only developed country that lacks a paid parental leave. This is particularly relevant to breastfeeding because the lack of paid leave is a major reason why women cannot initiate breastfeeding, meet dietary intake and nutritional guidelines during lactation, or maintain breastfeeding for the minimum recommended period. The paper therefore criticizes the conceptualization of breastfeeding as a personal responsibility and emphasizes the need for supportive policies, such as improving dietary fiber intake for mothers and paid parental leave.

While the public health implications of some microbiome findings are unclear, this is less true for others. Promoting the inclusion of fiber-rich whole foods into the diet of breastfeeding mothers and adopting a national, paid parental leave policy for all working mothers are *par excellence* of those implications in point.

Dietary Fiber and the Gut Microbiome During Pregnancy and Lactation

New research findings demonstrate that supporting the development of a diverse gut microbiome is of importance for human health. For instance, disrupting the growth of diverse gut microbiota reduces the strength of the immune system.[18] Health problems such as obesity, cardiovascular disease, cancer, and atopic diseases, such as allergies and asthma, have been shown to arise when the immune system is compromised due to a disturbance in the development of the gut microbiota.[19] Lifestyle choices and environments influence which species of bacteria and other microbes will inhabit the gut. The nutrients being consumed to cultivate the microbes help determine which species will colonize the gut and in what quantity.

Despite findings on the importance of diverse gut microflora, research has demonstrated that there has been a gradual decline in gut microbiome diversity in Westernized countries. This is cause for great concern, as greater gut microflora diversity is associated with health. Furthermore, recent research has demonstrated that some diet-induced extinction in a mother's gut is in turn transferred to the offspring, which might lead to irreversible loss of some microbial communities or species.[20] This depletion in microbial species has been most strongly linked to diets low in microbiota-accessible carbohydrates, or MACs. Dietary fiber is the main source of MACs for adults, and industrialized communities with diets low in dietary fiber tend to have comparatively higher rates of chronic non-communicable diseases like obesity, autoimmune diseases, asthma, and allergies, all of which are linked to disruptions in the host-microbiome relationship.[7]

The Institute of Medicine defines dietary fiber as referring to "non-digestible carbohydrates and lignins that are intrinsic and intact in plants."[21] Dietary fiber is present in plant-based foods such as whole grains, legumes, fruits, and vegetables. In a 9-year National Institutes of Health (NIH) cohort study of about 400,000 individuals ages 50 to 71, fiber was found to be significantly inversely associated with risk of death. Fiber intake from whole grains was most strongly associated with reduced risk of death in this study, followed by legumes and vegetables.[22] This cohort study found that fiber, especially from grains, was associated with reduced death from respiratory and infectious diseases, most likely because increased fiber intake is associated with reduced levels of inflammatory markers such as C-reactive protein, interleukin 6, and tumor necrosis factor α receptor 2. These markers all play a role in chronic inflammatory conditions that could increase risk of death.[21] The importance of fiber during pregnancy is related to improving digestion and regulation of glucose metabolism,[23] but fiber-rich diets during pregnancy have also been shown to reduce incidence of allergic diseases in infants.[24] The fiber and other nutrients found in whole grains, fruits, and vegetables support successful fetal development and breast milk quality by providing the vitamin B, folate, magnesium, and selenium needed for preventing spina bifida, anencephaly, low birth weight, and problems with the immune and nervous systems.

General overview of gut bacterial fermentation of fiber rich foods versus supplements

Bacteria are key to fermenting fiber because those residing in the colon ferment the dietary fiber carbohydrates that are not digested by the upper gastrointestinal tract. This fermentation process results in the production of methane, carbon dioxide, short-chain fatty acids (SCFAs) like acetate, propionate, and butyrate, and other metabolic products.[23,25] Each type of fiber consists of different types of molecular linkages and a different number of monosaccharide units. Humans do not produce their own enzymes capable of breaking down these polysaccharides; it is the bacteria in the small intestine and colon that are capable of performing this function.[26] Because of the structural discrepancies between types of fiber, many different enzymes are needed to break it down, and not every species of bacteria produces all the enzymes necessary to break down all types of fiber. Different species of bacteria work together as commensal organisms with varying capabilities to hydrolyze different dietary fibers; therefore, eating a variety of high-fiber foods such as fruits, vegetables, whole grains, and legumes can encourage greater microbial diversity and enhance metabolism in the gut. Dietary fibers can be classified as insoluble or soluble, depending on if they can be hydrolyzed in the gut. Insoluble fibers such as cellulose are not well fermented by gut microbes. Nevertheless, they can provide other health benefits by improving stool bulking and movement through the gastrointestinal tract.[23] Healthy sources of insoluble fiber include, but are not limited to whole-wheat flour, wheat bran, whole grain rice, nuts, beans and vegetables such as cauliflower and green beans.[27] Meanwhile, soluble fibers include B-glucans, pectin, inulin, resistant maltodextrins, resistant starch, polydextrose, and soluble corn fiber.[23] Oats, brown rice, peas, beans, apples, citrus fruits, carrots, and barley are some of the foods that contain significant amounts of soluble fiber.[26] Bacteria ferment soluble fiber, allowing them to perform beneficial functions such as producing SCFAs and lowering the pH of the gut.[28] A reduced pH helps prevent the growth of pathogenic microorganisms and reduces peptide breakdown and toxin formation.[29]

Can one take fiber supplements instead of following a high-fiber whole food diet and get the same benefits? Many fiber supplements are made from functional whole food fibers, yet they are physically, chemically, or enzymatically isolated from foods. Consumption of supplements (in pill or powder form) do not go through processing in the same manner by the gut microbiome when compared to fiber consumption from whole food forms.[20] Naturally high-fiber whole foods are known to be beneficial for health, partly because they contain other beneficial phytonutrients and phytochemicals.[30] Although some research has shown that fiber supplements might be prebiotic sources for gut microbes and can still be fermented by bacteria to produce SCFA,[31] they do not deliver the other key nutrients found in foods. Fruits and vegetables, for example, supply vitamins, minerals, antioxidants, and anti-inflammatory agents in addition to dietary fiber.[24] In pregnancy, the folate, vitamins, and minerals found naturally in high-fiber whole foods support fetal development.[22]

These nutrients would not be found in a typical fiber supplement. In addition, not all supplements are equally nutritionally beneficial and emerging evidence demonstrates inverse associations with health outcomes.[29,32,33]

What is the role of prebiotics for the gut? Prebiotics include certain fermentable (soluble) fibers and when derived from whole foods, there are other co-existing phytochemicals that promote the growth and/or metabolic activity of select species of commensal bacteria in the gut—traditionally called native gut bacteria, such as *Bifidobacterium* and *Lactobacillus*. These bacteria have multiple species within this genus that are considered beneficial to human health. Dietary fibers that are considered prebiotics include inulin, resistant starch, and oligosaccharides such as fructooligosaccharides, although other dietary fibers can also have prebiotic effects in the gut.[24,29] Galactooligosaccharides are also prebiotic. They are found naturally in human breastmilk, as one of the 130 different oligosaccharides that can be produced by lactating mothers.[34]

Galactooligosaccharides can also be manufactured from lactose to be added to foods as a fiber supplement.[33] Prebiotics from the diet and those naturally occurring in breastmilk can help the immune system develop and function more effectively, strengthen the gut barrier to protect against pathogens, and stimulate SCFA production by bacteria.[35] SCFAs have been shown to have benefits for human health by serving as an energy source for the colonic epithelium, influencing gut mucosal immunity and reducing gut inflammation. SCFAs are also absorbed into the bloodstream and can be used as an energy source for the brain, muscles, and tissues.[24,36] Fiber and breastmilk oligosaccharides also play key roles in ensuring proper immune responses.

Developing immune system linkages to gut fermentation of dietary fiber

Numerous studies have been conducted using mice to demonstrate the important immunological benefits of a diet rich in fiber. Mice fed diets that were comparatively higher in fiber showed reduced inflammatory responses in their lungs and gut. For lungs, this reduction in inflammation was shown through lower levels of inflammatory cytokines and antibodies and reduced mucus production in the lung tissue of mice fed a diet higher in fiber.[35] Reduced inflammation and mucous results in reduced airway resistance, which is important for proper breathing. Based on the study's findings, fiber reduces lung inflammation by providing the nutrients needed for gut microbiota to produce SCFAs. While SCFAs do not enter the lungs, they help to reduce dendritic cell (DC) maturation in other parts of the body. Therefore, when lung irritation does occur and these less mature DCs migrate to the lungs, they trigger a significantly reduced inflammatory response.[35] This study establishes how a high-fiber diet could be important for reducing asthma symptoms and airway inflammation. The availability of fiber allows gut microbes to produce metabolites that can influence systemic immune processes throughout the body.

Despite fiber's demonstrated role in the health of the human body, today's society is not meeting daily dietary fiber needs at all ages and stages of life, and has substantially reduced quantities (10-20 g/day) when compared to the diets of more rural societies and past generations (30-60 g/day).[19] This fiber-diet discrepancy over time and between populations may help explain differences in gut microbiome compositions and their metabolic functions. The recommended amount of daily fiber for adults is 30 g/day. Most Americans consume 15 g of fiber per day or less, which is 50% less than the daily amount recommended by the Food and Drug Administration (FDA).[28] Low dietary fiber results in reduced availability of MACs in the gut. This means that some commensal bacteria do not have the nutrients that they need to produce health benefits and optimal immune functions.[15] Importantly, mechanistic research that links the consumption of fiber to specific bacteria or microbial communities, and further to certain health outcomes, has typically risen from animal studies. Caution is often warranted to not assume that these mechanisms are identified and verified in humans. Given the rapid growth of research interests around the role of the human gut microbiota in facilitating beneficial health effects associated with consumption of dietary fiber, an evidence map of current research activity in this area was created using a newly developed database of dietary fiber intervention studies in humans.[30]

The beginning of an infant's life is a critical time for the establishment of gut microflora, with potential long-term health consequences if gut microbial dysbiosis occurs. For example, studies have shown that the first 100 days of life is a critical window—and little is known regarding how the wide variety of possible disruptions impact the formation of the gut microbiome during this time, all of which can put children at a higher risk of developing asthma and allergic disease.[37] There are four bacterial genera that, if present in children during this early phase of life, help to abate development of asthma and allergies. When mice were inoculated with these four types of bacteria (*Faecalibacterium, Lachnospira, Veillonella*, and *Rothia)*, they experienced significantly reduced lung inflammation, as levels of both neutrophils and leukocytes in the lungs were reduced. These findings indicate that gut microbiome development can play an important role in long-term immune system function, particularly relating to upper respiratory diseases like asthma.[36]

Beneficial human milk oligosaccharides

Breastfeeding has been shown to have many benefits for infant growth, especially in supporting the development of a healthy gut microbiome and immune system. The human milk oligosaccharides (HMOs) found in breastmilk provide important nutritional and other health benefits for infants. Oligosaccharides are the third most abundant nutrient in breastmilk behind lactose and fat, and serve as prebiotic soluble fibers for the infant gut. They consist of a combination of glucose, galactose, sialic acid, fucose, and N-acetylglucosamine linked together in different ways in each oligosaccharide, contributing to the diversity of prebiotics provided by breastmilk.[38] Because HMOs are prebiotic, they cannot be degraded by the infants' digest enzymes and can instead be fermented by bacteria in the colon. Not all bacteria can consume the oligosacchraides for nourishment, so the presence of HMOs fosters the growth of particular beneficial bacteria such as *Bifidobacteria* and *Bacteroides* while indirectly inhibiting the growth of other bacterial species.[39]

More than 200 unique HMOs have been identified in breastmilk.[39] The oligosaccharide content of breastmilk varies significantly from one woman to the next, and while additional research is needed, evidence indicates that the oligosaccharides are produced by a mother at a unique ratio to meet her infants' needs. The unique combination of oligosaccharides works together in a way that cannot be replicated by adding individual HMOs to infant formula.[40] In addition, the oligosaccharides vary based on the stage of lactation, diurnally, and based on the mother's genetic makeup.[38] The secretor and Lewis genes in the mammary gland determine the fucosylated sequences of HMOs, which serve as recognition motifs for bacteria.[41] These unique HMO structures allow fermentation by beneficial bacteria, while inhibiting and protecting the infant from pathogenic bacteria.[38]

An infant's diet plays an important role in the development of their gut microflora, which in turn will have a significant impact on their long-term health.[13,14] This is directly connected to breastmilk for at least those infants who are exclusively breastfed. Human milk contains beneficial species of bacteria such as *Bifidobacterium* and *Lactobacilli* that colonize the infant's gut, as well as oligosaccharides, which are fermented by commensal bacterial species in the colon. Breastmilk also contains secretory IgA, lactoferrin, and lysozyme. Lysozyme acts selectively to break down clostridia and other Gram-positive and Gram-negative bacteria while beneficial species of *Bifidobacteria* are resistant to its effects.[39] Many components of breastmilk work together to develop a diverse gut microbiome in the infant with long-term health benefits.

Research demonstrates that infants fed using formula rather than breastmilk do not receive these potentially beneficial bacteria and oligosaccharides.[42] A study by Borewicz et al[39] found statistically significant associations between the fecal microbiota composition of one-month-old breastfed infants and levels of two breastmilk oligosaccharides (LNFPI and 2'FL). LNFPI is positively associated with the presence of *Bacteroides* and *Bifidobacteria*, and 2'FL is positively associated with *Bacteroides*. Another study of 102 infants fed exclusively breastmilk, exclusively formula, or a combination of breastmilk and formula was conducted to investigate the impact the infant's diet had on his or her gut microbiome composition.[37] The results of this study indicated that there was no statistically significant difference between the gut microbiome composition of infants fed a combination of breastmilk and formula or exclusively formula, but there was a statistically significant difference between the microbiome of exclusively breastfed infants and the other two diets.[43] One of the differences in the microbiomes of the infants was that those who were exclusively breastfed had a greater abundance of *Bifidobacterium* in their guts. Oligosaccharides in breastmilk are thought to promote the growth of *Bifidobacteria*, and studies suggest that *Bifidobacteria* play a significant role in helping an infant's immune system mature.[44] Studies have suggested that HMOs are involved in the generation of anti-inflammatory mediators, T cell activation, and cytokine production. Acidic oligosaccharides may also play a role in preventing pathogenic bacteria from attaching to intestinal epithelial cells.[45] Animal studies have also supported the link between oligosaccharides and beneficial bacteria in the gut. A study using germ-free mice inoculated with *Bifidobacterium longum* subsp. *infantis* and *Bacteroides thetaiotaomicron* showed that the presence of HMOs provided *B. infantis* with an increase of 38% in relative abundance over *B. thetaiotaomicron.* This increase in abundance of *B. infantis* is important because it is a species of infant-associated bacteria that may keep pathogenic bacteria from growing extensively in the gut. *B. infantis* can also help produce SCFAs and other metabolites that are beneficial to the growth of helpful bacteria rather than harmful species.[46]

Breastfeeding has been associated with decreased risks of asthma, obesity, infection, metabolic syndrome, and diabetes when compared to infants fed with formula, and there is evidence linking gut microbe colonization through feeding with these health discrepancies.[42,47]

In sum, the recent literature on microbiome, as summarized in Table 1, highlights (1) the significance of fiber for human health, in general, and the significance of oligosaccharide components in breastmilk for infants' health during weaning in particular; (2) the importance of breastfeeding for infants' short- and long-term health; (3) prebiotic and probiotic supplements cannot be substitutes for a fiber rich whole foods diet; (4) different fiber-rich food groups, such as whole grains, legumes and vegetables, provide different benefits and should not be a replaced by one another; and (5) first 100 days are crucial for infants' gut microbiota to receive HMOs. Based on these research findings, the next section examines the existing dietary recommendations for lactating mothers and argues that the current recommendations should be modified to reflect the new research findings.

Existing Dietary Recommendations for Breastfeeding Mothers in the United States

Two major government agencies, namely the Centers for Disease Control and Prevention (CDC) and the US Department of Agriculture (USDA) provide dietary recommendations for breastfeeding mothers in the United States. CDC strongly recommends women breastfeed their newly born children for at least six months due to breastmilk's nutritional value and the fact that breastfeeding reduces risk for some health conditions for both infants and mothers. CDC's dietary recommendation, under the title of "Diet and Micronutrients" for breastfeeding mothers is quite straightforward and only consists of calorie increase in the maternal diet, iodine, iron, and vitamins B12, K and D (Table 2). These recommendations are consistent with the World Health Organizations' (WHO) recommendations, as discussed below.

More specifically, the CDC's dietary recommendation for breastfeeding mothers first includes an increase in calorie intake, by 450-500 kcal daily. Second, breastfeeding mothers are recommended to avoid seafood and caffeine. Third, all breastfeeding women and especially vegetarian and vegan mothers are encouraged to supplement with vitamin B12. Fourth, it is recommended that vitamins and minerals such as iodine, iron, vitamin D and vitamin K be present in the mothers' diet. Finally, the CDC encourages women to consult with the USDA *Choose My Plate* for more information on vitamins, minerals and calories needed during lactation. These recommendations are considered sufficient to increase the quality of the breastmilk and to avoid possibly harmful content. These recommendations make no mention of daily fiber intake needs of pregnant or lactating mothers, although they are referred to the USDA's *My Plate Daily Checklist*, as discussed next.

Choose My Plate is an online tool that provides dietary guidelines to any individual based on his or her characteristics, such as age, activity level, gender, pregnancy, and so on.[48] The program also gives dietary recommendations to lactating women based on the amount of breastmilk they provide to their children on a daily basis. Lactating mothers are recommended to avoid alcohol and caffeine, and they are advised to increase their daily fluid intake. *Choose My Plate* has a practical online tool that identifies the specific food categories and calculates the exact number of calories a lactating woman should consume. The program also identifies how many whole grain foods one should consume as well as the exact amount of vegetables, proteins, sugars, sodium and saturated fats, and so on. The online tool also enables entry of one's daily food items and thereby a comparison of the actual diet with the recommended modifications.

Although USDA's *Choose My Plate* program is a useful tool, it falls short when it comes to providing satisfactory dietary guidance to lactating mothers, and particularly when taking into consideration the evidence from recent microbiome research. First, the program fails to emphasize and highlight the significance of fiber consumption from whole foods. We tried to test the program by entering the characteristics of a lactating woman that we created. The program provided an analysis of the daily food intake for this mock character and made recommendations for how to follow a healthier diet. Accordingly, the program recommended 29 g of fiber/day, which is close to the FDA's recommended 30 g/day for adults. However, the recommended fiber amount was listed among 19 other nutrients including added sugar, Omega 3-EPA, Omega 3-DHA, Cholesterol, Linoleic Acid, Saturated fat, polyunsaturated fat, monounsaturated fat, a total of 9 minerals and 12 vitamins. Therefore, unless one already knows the significance of dietary fiber intake for lactating mothers, the recommended fiber amount could easily be overlooked.

Table 1. Literature on microbiome & breastfeeding-diet-fiber connection.

TOPIC	DETAILS	RESULTS
Relationship between fiber, the gut microbiome, and health	Comparison of diets and microbiomes between rural and industrial societies	High-fiber diets are associated with microbial growth in the gut that could help prevent non-communicable chronic diseases such as obesity, cardiovascular disease, allergies, and asthma.[18]
Relationship between fiber consumption and risk of death	9 year National Institutes of Health cohort study of about 400,000 individuals aging 50-71	Whole grains are most strongly associated with risk of death from respiratory and infectious diseases followed by legumes and vegetables as dietary fiber sources.[21]
Significance of fiber for both mother and fetus	High-fiber diets provide benefits during and after pregnancy	Fiber should be considered vital for pregnancy for variety of reasons including the prevention of constipation, cardiovascular disease during pregnancy and later childhood allergy development.[23]
Relationship between fiber, the gut microbiome, and health	Mechanisms of how fiber influences gut bacteria and human health	Fermentation of fiber by bacteria residing in the colon results in the production of methane, carbon dioxide, and short-chain fatty acids (SCFAs)—acetate, propionate, and butyrate. SCFAs serve as an energy source and support the immune system, among other functions.[28]
Gut bacteria and digestion	Analysis of how fiber/prebiotic consumption influences the behavior of gut bacteria	Commensal gut bacteria possess the enzymes necessary to break down certain polysaccharides (such as types of dietary fiber), providing health benefits that humans would otherwise be unable to enjoy.[25]
Fiber supplements vs high fiber whole foods	Analysis of how different types of fiber influence bacterial species and human health	Supplements are one option for meeting recommendations for fiber consumption, but eating whole grains, fruits, vegetables, and legumes provides dietary fiber as well as other benefits like antioxidants, vitamins, and minerals.[20,22,29,30]
Sources of dietary fiber		A variety of fruits, vegetables, whole grains, and legumes are good sources of insoluble and soluble fiber.[26]
Relationship between fiber, the gut microbiome, and health	Benefits of gut bacteria fermenting fiber	Bacteria can ferment soluble fiber in the colon, producing health benefits like short-chain fatty acids and a low gut pH.[27]
Significance of fiber for both mother and fetus	Health benefits of different types of prebiotics	Galacto-oligosaccharides are prebiotics found naturally in breastmilk, and are associated with increased growth of beneficial gut bacteria and protection from pathogens in breastfed infants.[31]
Relationship between fiber, the gut microbiome, and health	How prebiotics contribute to human health	Prebiotics health maintain a strong immune system, protect the gut barrier from pathogens, and stimulating short-chain fatty acid production by bacteria.[32]
Relationship between fiber, the gut microbiome, and health	Mouse study on relationship between fiber consumption and immune system	Mice fed a high-fiber diet presented with reduced inflammatory responses in their lungs and gut. Based on the study's findings, fiber reduces lung inflammation by providing the nutrients needed for gut microbiota to produce short-chain fatty acids.[33]
Infant gut microbiome development and immune system function	Mouse study connecting specific bacteria to an effective immune system	If the growth of a gut microbiome is disrupted during this time, children are at a higher risk of developing asthma and allergic disease. Mice inoculated with four genera of "healthy" bacteria experienced reduced lung inflammation.[29]
Breast milk and infant gut microbiome	Effects of breast milk on infant gut microbiome in a longitudinal study and meta-analysis	Diversity and composition of infant microbiome was dependent on the daily intake of breast milk and differences in the relative abundance and functions of particular bacteria are shown in the comparison of exclusively breastfed to non-exclusively breastfed infants across populations.[13,14]
Breastfeeding vs formula feeding and the gut microbiome		Infants who are fed using formula do not receive the beneficial bacterial strains and oligosaccharides found in breast milk.[34]
Breastfeeding vs formula feeding and the gut microbiome	Cohort study of microflora composition of formula vs breastmilk-fed infants	There is a statistically significant difference in the gut microbiomes of infants who are exclusively breastfed compared to formula-fed infants or infants fed a combination of formula and breast milk.[35]
Maternal microbiome and offspring immune development	No fiber diet vs high fiber diet fed mice on T cell development in offspring	Maternal dietary fiber derived short chain fatty acids effect offspring immune development through promotion of regulatory T cell differentiation by increasing autoimmune regulator expression.[36]
Breastfeeding vs formula feeding and the gut microbiome	Prebiotics in breastmilk	Oligosaccharides are prebiotics found in breast milk that promote the growth of *Bifidobacteria* in infants, a strain of bacteria that is beneficial for the immune system.[30]
Breastfeeding and the gut microbiome	Prebiotics in breastmilk and the immune system	Studies suggest that milk oligosaccharides strengthen the immune system through generation of anti-inflammatory mediators, T cell activation, cytokine production, and preventing the attachment of pathogenic bacteria in the gut.[37]
Breastfeeding and the gut microbiome	Study on relationship between milk oligosaccharides and commensal bacteria	A study using germ-free mice demonstrated that human milk oligosaccharides increased the growth of *Bifidobacterium longum* subsp. *infantis* bacteria, which help fight pathogenic bacteria and produce short-chain fatty acids and other metabolites.[38]

Table 2. Centers for Disease Control and Prevention (CDC)'s Breastfeeding Recommendation for Diet and Nutrition for Lactating Mothers.

Diet • Additional 450 to 500 kcal; avoid seafood and caffeine (including coffee, sodas, energy drinks, tea and chocolate) • Vegans or lacto-ovo vegetarians should supplement with B12.	Vitamin B12
Iodine	Vitamin D
Iron	Vitamin K

Source: CDC home page at https://www.cdc.gov/breastfeeding/breastfeeding-special-circumstances/diet-and-micronutrients/index.html.

Table 3. Recommended Policy Changes Concerning Lactating Mothers' Diet.

Minimum daily dietary fiber	30 gr.
Sources of fiber	Whole grains (brown rice, oats, wheat, rye) Legumes (common dry beans, lentils, chickpeas) Vegetables (peas, green beans, leafy greens, carrots)

Second, the program rightly emphasizes the significance of following a whole foods diet rather than relying on supplements. This is a key recommendation we support. However, it does not specify the recommended sources of fiber, such as whole grains, legumes, fruits and vegetables. As the literature review above discusses, different food groups provide different fiber contents with varying benefits. Thus, one should not only focus on the total fiber amount recommended, but one should also make sure to consume fiber from diverse sources that contain other essential micronutrients, and not rely on manufactured fiber supplements. Third, the literature review emphasizes the significance of consuming whole grains as the main source of fiber. Again, no such emphasis is made by *Choose My Plate*. Therefore, we strongly recommend that the modifications (listed in Table 3) are made to the dietary recommendations by both CDC and USDA's *Choose My Plate*.

Unfortunately, the WHO recommendations also fall short when it comes to fiber. The WHO gathered information about the national policies of the member countries concerning pregnancy and lactation. The information was collected in 2014 through a questionnaire sent by WHO to 53 member states of the WHO European Region.[49] Accordingly, 41 out of 53 countries have national recommendations on nutrition for pregnancy while 33 have for the postpartum period. Although these recommendations emphasize that pregnant women and lactating mothers should consume whole foods from diverse sources, they do not go beyond vitamins and minerals and fiber is not mentioned in these recommendations at all. It should be highlighted that the recommended list is longer than that of the United States.[49] In sum, there is an urgent need to revise the dietary recommendations both in the United States and by the WHO based on emerging research findings linking dietary fiber consumption and breastmilk oligosaccharides to the development of a diverse gut microbiome in the infant.

Bridging discussion of dietary fiber recommendations and parental leave policy

It is often the case that breastfeeding recommendations are discussed independently from a woman's ability—or the lack thereof—to breastfeed her child. This approach is closely related to a particular conceptualization of breastfeeding, which considers it primarily an individual responsibility and that the best a policy can do is help women make the best decision. The ultimate responsibility lies with the individual. An alternative approach is to consider the feasibility of following breastfeeding guidelines and support additional policies to facilitate make breastfeeding more practical. This paper takes this alternative approach and therefore contends that the parental leave policy should be adopted to facilitate the breastfeeding initiation and maintenance. As discussed below, research shows that in countries where there is a national parental leave policy that guarantees the replacement of mothers' income (in part or fully), such as Sweden and Norway, the breastfeeding initiation and maintenance rates are the highest, compared to the United States which lacks a paid maternity leave policy.

The diets of lactating mothers and their impact on oligosaccharides and other breastmilk contents are only relevant if women have the resources and the time to maintain a healthy diet needed for breastfeeding. The-cross country comparison is striking: Data show that only a small percentage of women (15%) in the United States breastfeed their children exclusively for 6 months, which is the recommended period by the CDC, while 1 out of every 4 (25%) women never initiate breastfeeding in the first place. This is a striking difference from Norway, for instance, where mothers can take up to 46 weeks of leave and receive 80% of their pay, the breastfeeding initiation rate is as high as 99% and the maintenance rate after six months is 80%.[17] In Sweden, similarly, about 60% of babies are still breastfed at four months. When asked, women in the United States clearly articulate the reasons behind these low breastfeeding rates: surveys have revealed women's work-related requirements constitute a major reason behind their decisions, as discussed below. Thus, any discussion on public policy concerning infant microbiome must include both the dietary recommendations for lactating mothers and the paid leave policies. This point is particularly relevant to the United States as it is *the only* Organisation for Economic Co-operation and Development (OECD) country that does not guarantee any paid maternity or parental leave.

The relationship between breastfeeding and paid maternity leave has been clearly and explicitly established by the WHO, which recommends at least six months of exclusive breastfeeding as well as "six months of mandatory paid maternity leave and policies that encourage women to breastfeed in the workplace and in public."[50] The WTO identifies the maternity leave as part of the conditions that create a supportive environment for breastfeeding. This approach is in line with the approach that this article is taking. For instance, according to the 2016 report by the WHO's Regional Office for Europe, maternal and infant health are best understood with a holistic approach.[49] This means that the preconception, pregnancy and postpartum health of women needs to be considered along with what the report calls "supportive environmental conditions" which include much needed changes pertaining to maternity leave and return-to-work legislation (pp. 15-16). This is a more comprehensive and holistic approach to public policy than the conception of individual responsibility currently adopted by the United States The latter fails to create a supportive environment conducive to breastfeeding and places a heavy burden on women, as discussed below.

Breastfeeding and Parental Leave: A Public Health Issue

The percentage of mothers who breastfeed in the United States is alarmingly low and even lower for Black women: The CDC reports that Black infants are 21% less likely to have ever been breastfed than white ones.[51] According to CDC, low rates of breastfeeding adds more than $3 billion a year to medical costs in the United States because "breastfeeding provides unmatched health benefits for babies and mothers." Specifically, the benefits for infants include the reduced risks of asthma, obesity, Type 2 diabetes, ear and respiratory infections and sudden infant death syndrome (SIDS) while the benefits for mothers include the lower risks of heart disease, Type 2 diabetes, ovarian cancer and breast cancer.[51] Recent microbiome research has shed light on integrated diet-microbe-host interactions as mechanisms through which these diseases develop and progress. As discussed in the literature review above, the oligosaccharide content of the breastmilk plays a crucial role in the prevention and control of many common chronic disease conditions.

The CDC identifies contributing factors to the low rate of breastfeeding in the United States as less than ideal hospital practices, lack of education and encouragement, the lack of policies and support in the workplace, and the absence of community support. As part of its initiative to promote breastfeeding, the CDC continues to work with a number of stakeholders including hospitals, doctors, birth centers, worksites and communities, and partners with states to "help employers support breastfeeding mothers with places to pump and store milk, flexible work hours, and maternity leave benefits."[47] These initiatives have positively brought the percentage of mothers who begin breastfeeding shortly after birth from 73% in 2004 to 83% in 2014.[52] There were other efforts on a national level to raise awareness about breastfeeding. For instance, the Affordable Care Act (ACA) of 2010 tried to partly address the workplace accommodation for working mothers by including a provision to help mothers pump their milk at work.

This was also recommended by the International Labor Organization (ILO) as well the WHO and the United Nations International Children's Emergency Fund (UNICEF), although the WHO's recommendation goes beyond this limited workplace accommodation. The WHO recommends exclusive breastfeeding for the first 6 months, followed by breastfeeding in conjunction with food up to 2 years:

> Governments were urged to act upon their obligations and take all necessary measures to protect, promote, and support breastfeeding, and end the inappropriate promotion of breast-milk substitutes and other foods intended for infants and young children up to the age of 3 years. These measures include the adoption and enforcement of comprehensive legislation to end inappropriate marketing practices, provide adequate maternity protection, and protect women from discrimination linked to breastfeeding.[53]

The WHO calls governments to enable breastfeeding with legislation that includes maternity leave policies.[54] Thus, the benefits that came with the ACA fall short in following the WHO's recommendation.

We wholeheartedly support the initiatives by CDC and any other agency and applaud the changes made through ACA to increase the number of breastfeeding mothers and to educate various stakeholders for that purpose. A major weakness of these initiatives is that breastfeeding is still being considered a personal responsibility of the mother, with a focus on increasing women's awareness about the significance of breastfeeding for their infants' and their own health. It is our deep conviction that unless structural issues are addressed through a national leave policy, the success of these initiatives will be limited. Indeed, despite all these efforts, the rate of exclusive breastfeeding during the recommended minimum period remains disturbingly low. As the CDC acknowledges, "employed mothers typically find that (1) returning to work and (2) lack of maternity leave are significant barriers to breastfeeding."[55]

Conceptualizing breastfeeding as a personal responsibility is flawed at least on two grounds. First, it ignores the fact that many working mothers must go back to work within the first year after the infant's date of birth. Not returning to the workplace means losing income that is crucial for their survival. Research has constantly demonstrated that women's employment is negatively associated with breastfeeding.[56] According to labor statistics of 2016 by the Department of Labor, 68% of women who have children under the age of three are employed (US Department of Labor, 2016).[57] Research has also demonstrates that mothers who are employed full time have similar initiation rates as those women who do not work; however, they wean their children prematurely at a higher percentage than women who do not work outside home.[56] It is important to note that these numbers do not include those women who either dropped out of the labor market before pregnancy or did not seek employment due to the expectation of pregnancy and breastfeeding. In sum, leaving work due to birth is not an option for many women who must earn an income, and the ability to breastfeed while working depends on multiple occupational conditions, such as the employer's collaborationthe nature of the work, and other factors. that are beyond a woman's control.

Furthermore, women who can afford temporarily leaving the labor market will face other consequences. A depreciation of skills in a rapidly changing labor market leads to women struggling to find employment again, and when they do, they are less likely to be employed in the same kind of work they did before. In the absence of a paid parental leave, it is often the case that a traditional gender division of labor, which makes women full time-home makers and men work outside home is likely to result in increased household responsibilities for women in the long term. Therefore, we advocate a more equitable arrangement, that is parental leave rather than a maternity leave, which would allow breastfeeding women to leave their work without facing income loss or unemployment, and allow men to take a paternal leave and share the responsibilities of caring for an infant.

As mentioned above, other developed countries seem to have a better record when it comes to providing paid maternity leave. For instance, according to the 2016 report by the WHO Regional Office for Europe, 48 out of 53 countries have a national, fully or partially paid maternity leave. Furthermore,

> 15 countries (28%) have fully paid paternity leave adopted into national legislation, while only partially paid leave is possible in a further 8 countries (15%). Five countries (9%) provide both fully and partially paid paternity leave is possible in a further 8 countries (15%). Five countries (9%) provide both fully and partially paid paternity leave. A total of 13 countries reported that both maternity and paternity leave can be used simultaneously.[49]

According to the report of the ILO, typically developed countries provide a national maternity leave either fully or partially paid.[58] Many developed countries have also incorporated paternity leaves as part of their parental leave policy, as in the case of some OECD countries, such as, Norway, Sweden and Finland.[59] Paid maternity leaves leads to women initiating breastfeeding and maintaining the practice for longer lengths of time.[60]

Paid leave policy seems to enjoy strong public support in the United States: in a public survey conducted in 2015, almost 70% agreed that there should be paid leave policy and only about 10% of the interviewees disagreed with this statement.[61] Given the significance of breastfeeding for future generations, the burden of breastfeeding cannot be left to the market or women's bargaining power. This is clearly a public health issue, which requires a publicly shared solution.[62]

Developing a national parental leave policy will obviously require making decisions on a number of issues, such as the duration of the paid leave, the share between pre- and post-birth leaves, distribution of time between the mothers and fathers, whether or not the leave will include home care leave, and who will pay for the cost. These details could be determined through discussions among stakeholders and comparative studies of successful examples of paternal leave policies.[55,63] As our discussion above explains, a national parental leave policy should be also accompanied by other supporting practices that the CDC has been recommending for decades, such as the measures to support breastfeeding after women return to work. These measures require the involvement of a series of stakeholders including hospitals, doctors, birth centers, and worksites, so that mothers can pump and store milk at work and enjoy flexible work hours. As these changes increased the breastfeeding rate in 2014, these are important measures and should be highlighted to increase the breastfeeding rates particularly when combined with a paid parental leave.

Conclusion

Recent microbiome research has highlighted that there exists a small window of opportunity to establish the infant microbiome. The child's body and immune system develop rapidly and significantly during the beginning of his or her life, and this window of opportunity is key to preventing common diseases that put an extraordinary burden not only on the child and his or her family, but on the existing health care system. Treatments come with significant costs and reduce overall quality of life. Recent research has demonstrated that some diet-induced extinction in the gut microbiota has already taken place in Western populations, which is then transferred to the offspring, which might lead to irreversible loss of some species. Crafting public policies require meticulously weighing the expected benefits and the expected risks. The policy changes recommended in this paper pose no known risk while the expected benefits are high. Promoting fiber-rich foods in the diet of breastfeeding mothers and facilitating breastfeeding through a nation-wide, paid parental policy are low hanging fruits with enormously significant benefits for the public at large.

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