Fiber in enteral nutrition: why and what for?

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ABSTRACT

Enteral formulas containing fiber, designed to be administered orally or by gavage, have been used for decades. Although their indication in the pediatric population does not have a global consensus, knowledge about the benefits of using fiber to promote healthier microbiota has grown in recent years. Different fiber types' physicochemical characteristics (solubility, viscosity, fermentability) determine their functions. The impact of fiber use on preventing specific chronic pathologies (cardiovascular disease, cancer, diabetes) has been reported in epidemiological studies. In controlled studies, changes in stool consistency, intestinal transit, and the composition and function of the microbiota have been observed since fiber produces fermentation metabolites such as short-chain fatty acids, which improve metabolic and immunological aspects. Different pediatric pathologies could benefit from the use of fiber.

Keywords: *fiber; enteral nutrition; microbiota; short-chain fatty acids.*

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INTRODUCTION

In the last decades, progress has been made in using enteral nutrition (EN) in different pediatric pathologies.[1] At the same time, formulas with fiber have been developed that cover the nutritional requirements of different patients and promote a healthier intestinal microbiota (IM), regulate intestinal function, improve the structure of the intestinal barrier, and improve immune function.[2]

This work consists of a non-systematic review of the narrative type of the subject matter of the article. The authors jointly elaborated questions, and the answers were developed according to each author's specialty through a review of published studies indexed at https://pubmed.ncbi.nlm.nih.gov/. Those that each author considered relevant to include in this manuscript were selected. The keywords used for the literature search were *microbiota, microbiome, fibers, prebiotics, enteral nutrition,* and *tube feeding*.

WHAT IS ENTERAL NUTRITION? WHAT ARE ITS INDICATIONS?

EN is the administration of nutrients through feeding tubes and oral nutritional supplementation.[3] In practice, it is indicated in pathologies presenting inadequate intake, reduced tolerance, or increased nutritional requirements (*Table 1*).[4]

It is often the only feeding route, so it should cover all the nutritional needs for the child's growth and development.[5,6] Other objectives of EN are to avoid the adverse effects of prolonged fasting on gastrointestinal function and structure and to provide nutrients with beneficial effects on the intestinal mucosa and its barrier mechanisms (e.g., omega-3 fatty acids, prebiotics, and fiber).[7]

WHY IS IT IMPORTANT FOR ENTERAL NUTRITION TO CONTAIN FIBER?

Epidemiological studies have shown the relationship of fiber intake with a decrease in the incidence of different chronic diseases (cardiovascular disease, cancer, diabetes) and the associated risk of death.[8,9] Moreover, controlled clinical studies report on fiber intake's beneficial effects on the intestine: better absorption of nutrients, transit time, stool formation, and IM composition and function. The use of fiber generates, through its fermentation, metabolites such as short-chain fatty acids (SCFA), which exert critical gastrointestinal effects, including metabolic effects and effects on immune function.[10]

WHAT DO WE MEAN BY THE TERM *FIBER*?

Dietary fiber has different definitions worldwide, depending on scientific and regulatory institutions. The World Health Organization and the *Codex Alimentarius* (CA) consider fiber a set of carbohydrates that are neither digested nor absorbed in the small intestine and have a degree of polymerization more significant than ten monomeric units.[11] This fiber includes non-starch polysaccharides, such as cellulose, hemicelluloses, and pectins; resistant starch and non-digestible oligosaccharides, such as inulin and oligofructose; and lignins. Based on their physicochemical properties, the different fibers are classified as soluble, viscous, or fermentable[12] (*Table 2*). Solubility refers to the ability to dissolve in water; fermentability refers to the degree to which IM microorganisms can metabolize them; and viscosity refers to the possibility of forming a consistency similar to an aqueous gel. Soluble and fermentable fiber has the most

Table 1. Indications for enteral nutrition in pediatrics (adapted from Pedrón-Giner et al.)[4]

Indication	Pathologies
Difficulty in ingestion/swallowing	CNPE, critically ill patients, PTNB, neuromuscular diseases, ED
Difficulty in digestion/absorption	Short bowel syndrome, severe or prolonged diarrhea, intestinal motility disorders, hepatopathies
Non-digestive diseases with increased requirements	Renal diseases, congenital heart disease, oncological pathologies
Diseases for which EN is a critical part of the treatment	Inborn errors of metabolism, Chron's diseases
Other	Short bowel syndrome, malnutrition, surgical pathologies

CNPE: chronic non-progressive encephalopathy, ED: eating disorders, EN: enteral nutrition, PTNB: preterm newborns.

significant effect on IM, as insoluble fiber is not fermented but contributes only to the bulk of the stool. Combining these three physicochemical characteristics determines the functional effects in the intestine. For example, the fibers in the lower left corner of *Figure 1* (insoluble, non-viscous, and non-fermentable) have functions related to intestinal transit time. Fibers in the lower right corner (soluble, non-viscous, and fermentable) have functions related to the microbiome and fermentation; and fibers in the upper right corner (soluble, viscous, and fermentable) have functions related to the microbiome, fermentation, and nutrient bioavailability. Fibers in intermediate positions have intermediate functional properties.[12]

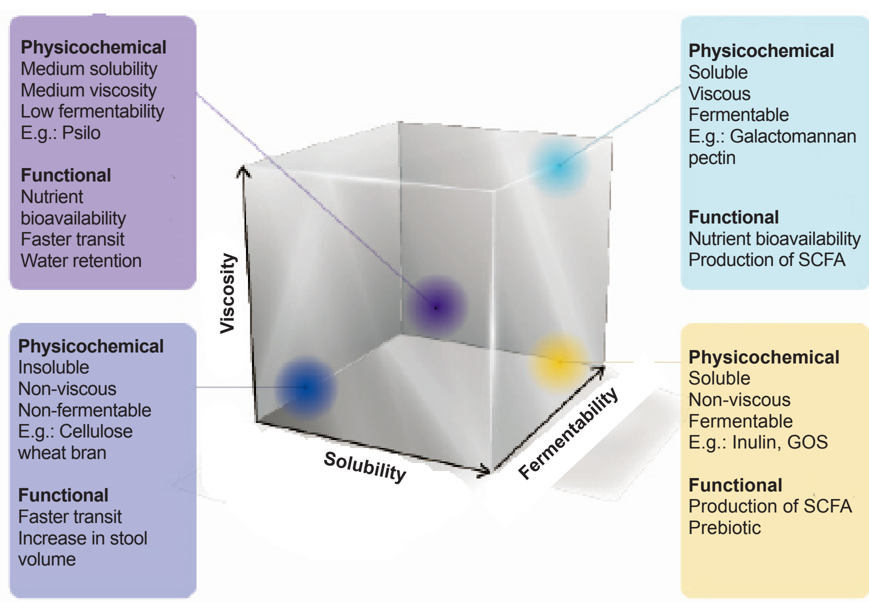
WHAT IS THE EFFECT OF FIBER ON THE INTESTINAL MICROBIOTA?

From the onset of complementary feeding and throughout the life course, adequate fiber intake favors the development of healthy bacteria, with an impact on the diversity and abundance (eubiosis) of the IM.[12,13] A dietary pattern low in fiber can irreversibly reduce microbial diversity. In early life, IM contributes to the homeostatic regulation of different body organs; its disruption can lead to dysfunction and the development of chronic diseases, such as inflammatory bowel disease (IBD), colorectal cancer, allergies, autoimmune diseases, and obesity.[8,9,13] These diseases can be prevented, at least in part, by adequate dietary fiber intake. In practice, less developed and rural populations that consume

Table 2. Physicochemical properties of the different types of fiber (adapted from Gill et al.)[12]

Fiber type	Solubility	Viscosity	Fermentability
Cellulose	Insoluble	Non-viscous	Low
Lignins	Insoluble	Non-viscous	Low
B-glucans	Low-medium	Medium-high	High
Pectins	High	Medium-high	High
Inulin	Medium-high	Low-high	High
Galacto-oligosaccharides	High	Low	High
Dextrins	High	Non-viscous-low	High
Guar gum	High	Low	High

Figure 1. Physicochemical characteristics of different dietary fibers (adapted from Gill et al.)[12]



GOS: galacto-oligosaccharides, SCFA: short-chain fatty acids.
The physicochemical characteristics of the fiber (solubility, viscosity, and fermentability) interact with each other and form a continuum that determines its functional properties in the gastrointestinal tract.

more fiber than urban or industrialized populations have a lower prevalence of these diseases.[13]

Fiber provides substrates that are fermented by specific genera of strictly anaerobic bacteria (*Bifidobacterium*, *Akkermansia*, *Faecalibacterium*, *Ruminococcus,* and *Christensenella*) that possess the enzymes to degrade complex carbohydrates that are not digested in the small intestine and reach the colon. Specific fiber types may require multiple enzymatic catalysis steps to produce SCFA (butyrate, propionate, and acetate), the main product of microbial metabolism. The amount of SCFA produced depends on the type and amount of fiber consumed and the bacterial species in the colon.[12,13]

HOW DOES FIBER ACT IN THE GASTROINTESTINAL TRACT?

SCFA derived from fiber fermentation regulate different biological processes in the host, acting as chemical messengers and molecular signals, on metabolism, motility, secretion, the intestinal barrier, and immunomodulation.[12,13] They are found in high concentrations in the cecum and proximal colon, where they act directly and indirectly: they are used as a source of energy by colonocytes (primarily butyrate). They can be transported to the peripheral circulation through the portal vein to act on the liver and peripheral tissues.

Fiber *per se* modulates intestinal transit and delays gastric emptying, thus reducing or slowing small intestinal glucose absorption and fasting and postprandial glucose and insulin levels.[12,13] In addition, via the production of SCFA can positively modify glucose metabolism: butyrate acts as a signal through receptors of hormone-producing enteroendocrine cells, which in the blood circulation constitute essential keys in glucose and lipid metabolism. Together with propionate, they increase intestinal gluconeogenesis and decrease hepatic gluconeogenesis. Acetate, on the other hand, acts on the regulation of satiety in the centers of the central nervous system (CNS), forming part of the brain-gut axis.[13,14]

The effects generated by SCFA on intestinal motility are related to receptors of motor migratory complexes and enteric neurons of the enteric nervous system (ENS) located below the intestinal mucosa, which respond to signals from the IM that modulate intestinal function. SCFA also stimulate enterochromaffin cells to release 5-hydroxy-tryptamine (5-HT serotonin), with action on colonic and ileal enteric muscle.[15,16] Through their effect on receptors in intestinal cells, they can regulate the secretion and absorption of water and electrolytes in colonic cells. Thus, alterations in IM (dysbiosis) are associated with functional gastrointestinal disorders and dysmotility (abdominal pain, diarrhea, or constipation).[17]

IM can also influence interactions between the gut and the central nervous system (CNS) through multiple signals that form the bidirectional microbiota-gut-brain axis. The IM modulates axis communication to and from the CNS with neurotransmitters, mainly 5-HT, and the vagus nerve. CCFA stimulate the release of 5-HT with receptors widely expressed in vagal afferent pathways.[15,16]

IM also influences intestinal permeability. Dietary fiber and SCFA stimulate mucus production and secretion by goblet cells and promote the stability of epithelial junctions (tight junctions). A prolonged lack of fiber is associated with an increased abundance of bacteria that degrade the protective mucus and damage the intestinal barrier.[12,13,18,19]

Healthy IM contributes to the maturation and development of the immune system in the first two years of life. SCFA have anti-inflammatory and immunomodulatory effects, as they can induce the proliferation and differentiation of regulatory T cells in the colon, which release anti-inflammatory cytokines and prevent the development of intestinal inflammation. Because of this role, dysbiosis may favor the development of autoimmune diseases, inflammatory bowel disease, celiac disease, and food allergies, among other pathologies.[12,13,18,19] The mechanisms of fiber action are shown in *Figure 2*.[12]

WHAT IS THE RECOMMENDED DOSE OF FIBER IN CHILDREN AND ADOLESCENTS?

Fiber requirements vary by regulatory authority (*Table 3*).[20] There is no universal consensus on the dose of fiber that should be used in enteral-fed children with acute or chronic disease.

HOW TO IMPLEMENT FIBER ADMINISTRATION?

EN formulas contain different fiber types, and there is no universal agreement on its indication. In a consensus for the treatment of infants with neurological disorders,[21] the recommended nutritional indication is a polymeric formula with fiber. In an expert review of the European Society of Pediatric Gastroenterology, Hepatology, and Nutrition,[20,22] it was concluded that fiber should be considered in all patients receiving EN, with a slow introduction starting at 6 months of age. Tolerance should be observed in each case. A mixture of fermentable fibers with a prebiotic effect would be the best option in the long term.

In infants under 6 months of age, this effect is achieved through human milk, which provides oligosaccharides (HMO), while infant formulas provide short-chain galactooligosaccharides (GOS) and long-chain fructooligosaccharides (FOS) (GOSsc/FOSlc) in a 9:1 ratio; and are the most frequently used.[23-25]

WHICH PEDIATRIC PATHOLOGIES BENEFIT FROM THE USE OF ENTERAL NUTRITION WITH FIBER?

The use of fiber is a preventive strategy due to its proven benefits on IM and its effect on intestinal transit, stool volume and consistency, and intestinal mucosa, with decreased permeability and improved immune response.[12,17,20,26]

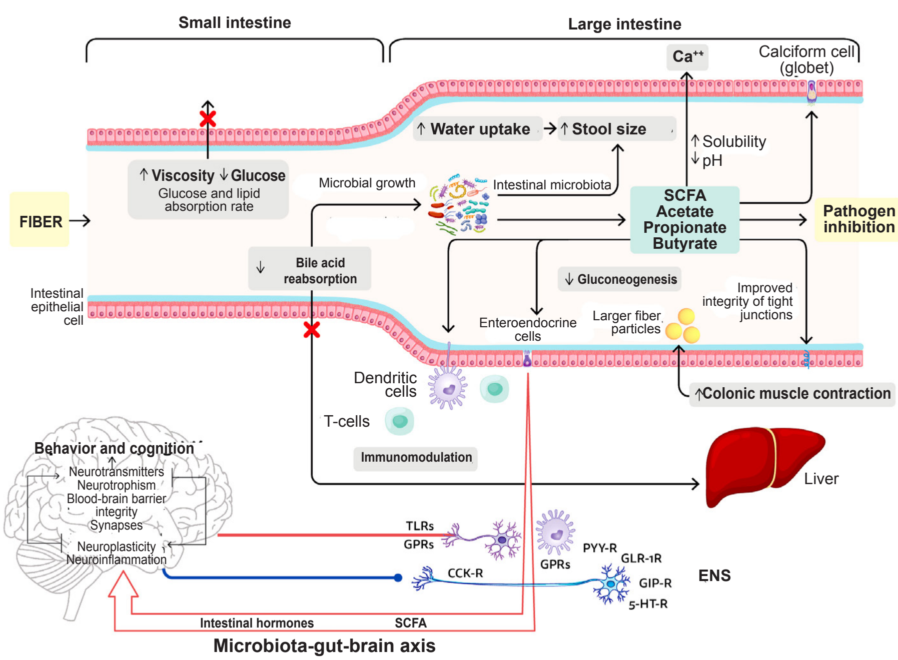
The use of fiber in enteral feeding formulas is indicated in any patient older than 6 months who requires prolonged nutritional support and is currently considered as first-line nutritional

Table 3. Fiber requirements according to regulatory authority (adapted from Lionetti et al.)[20]

EFSA (Europe)		SACN (United Kingdom)		IOM (United States of America)		NHRMC (Australia)	
Age (years)	Reference value	Age (years)	Reference value	Age (years)	Reference value	Age (years)	Reference value
1-3	10 g/day	2-5	15 g/day	1-3	19 g/day	1-3	14 g/day
4-6	14 g/day	5-11	20 g/day	4-8	25 g/day	4-8	18 g/day
7-10	16 g/día	11-16	25 g/day	9-13	26 g/day (girls)	9-13	20 g/day (girls)
11-14	19 g/day	16-18	30 g/day		31 g/day (boys)		24 g/day (boys)
15-17	21 g/día			14-18	26 g/day (girls)	14-18	22 g/day (girls)
					38 g/day (boys)		28 g/day (boys

EFSA: European Food Safety Authority, SACN: Scientific Advisory Committee on Nutrition, IOM: Institute of Medicine, NHRMC: National Health and Medical Research Council.

Figure 2. Mechanisms by which different dietary fibers affect the gastrointestinal tract and the gut-brain axis (adapted from Gill et al.)[12]



ENS: enteric nervous system, SCFA: short-chain fatty acids.

therapy;[20] for example, pediatric post-surgical patients, critically ill patients who have been fasting and therefore require EN,[27] neurological patients,[21] malnourished,[5] with short bowel syndrome,[28] and with inflammatory bowel disease (IBD) in remission.[12,29]

Given the individual variability of response to fiber intake, it is still complex to determine which type of fiber is appropriate for each gastrointestinal disorder. The fiber's characteristics, the patient's clinical condition, and the fiber tolerance should be considered to optimize the benefits.[30] Experts advise progressive administration and continued intake according to tolerance.[20]

CAN FIBER GENERATE ADVERSE EFFECTS?

With the incorporation of fiber in formulas, physiological effects similar to those of a regular diet with mixed fiber or fiber blends can be observed, such as increased gas production and softer stools.[31]

Studies show good tolerance and decreased diarrhea in children on enteral nutrition with fiber-containing formulas due to their beneficial effect on IM.[32]

In a systematic review of the use and safety of fiber in critically ill patients, in which gastrointestinal symptoms (diarrhea, abdominal distension, residual gastric volume, vomiting, and constipation), IM, length of stay in the intensive care unit, and death were analyzed, it was shown that the use of soluble fiber in all critically ill, hemodynamically stable patients is safe and well tolerated. It should be considered beneficial in reducing gastrointestinal problems.[33]

In a double-blind, randomized, crossover study to investigate the effect of multifiber supplementation on gastrointestinal function for prolonged periods in children with cystic fibrosis, neurological conditions, post-liver transplant, post-bone marrow transplant, or renal conditions, no adverse effects were observed.[27]

Although there are no specifically defined contraindications, its use is not recommended in patients with obstruction, intestinal stenosis, and acute inflammation, and its introduction should be established and evaluated according to the patient's tolerance.[12]

WHAT IS THE EVIDENCE FOR ENTERAL NUTRITION PRODUCTS OR SUPPLEMENTATION WITH FIBER MIXTURE?

The first randomized controlled trial investigating the effects of a hypercaloric oral supplement (2.4 kcal/ml, 125 ml) given for one month to children (5-6 years) with growth failure showed a significant improvement in intake and growth. The product contained 3% (w/v) of a mixture of 80% soluble fibers (acacia, inulin, and oligofructose) and 20% insoluble fibers (cellulose, soy polysaccharide, and resistant starch). There were no fiber-related adverse effects in both groups.[34]

For products containing 0.8% (w/v) of a 1:1 blend of the above fibers, the ability to reduce days of constipation was demonstrated in children aged 4 years of middle age (range 10 to 60 months) who required EN, concerning the control group without fibers.[35]

In a study in adults, where the majority received exclusive EN, administering a multifiber product relative to the non-fiber control induced a significant increase in the concentration of SCFA in fecal matter and in total fecal bacterial counts.[36] In a randomized, controlled, double-blind, crossover trial involving 27 children (80% neurologically impaired) aged 11.9 ± 3.9 years with EN, a significant increase in the proportion of fecal bifidobacteria was observed during the multifiber period, relative to the non-fiber period, along with a significant reduction in fecal pH.[37]

CONCLUSIONS

The beneficial effect of fiber on the composition and function of IM, gut barrier function, mucus production, gut immune function, and the CNS via the gut-brain axis is well recognized. Oral or gavage EN should consider the patient's nutritional and fiber requirements. However, there has yet to be a global consensus on the daily amount of fiber according to age range. Including fiber in EN in different patient groups, even in the case of gastrointestinal disease, should be encouraged because of its beneficial effects on healthy microbiota development. Given the individual variability of the response to fiber intake, most likely associated with differences in the composition and function of the microbiota, it is still complex to determine which type of fiber, or combination of fibers, is the most appropriate for different pathologies. New studies are needed to analyze these aspects in depth. ■

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