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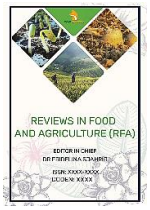

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REVIEW ARTICLE

THE INTERPLAY BETWEEN THE GUT FLORA AND MICRONUTRIENTS: THE KEY TO MODULATING MINERAL AND VITAMIN BIOAVAILABILITY

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ABSTRACT

Impacts on both short and long-term health are severe in the case of deficiencies in micronutrients, such as vitamins and minerals. An important cause underlying these reduced bioavailability is probably reduced caloric intake and/or insufficiency in absorption in the gastrointestinal system. The gut microbiome is now apparently playing an important role recently seen from clinical and in vivo studies. In fact, the level of micronutrients can be regulated by commensal bacteria in interference with biosynthetic processes and through alteration of the absorption process. The study discusses the mechanisms by which gut microbiota affects absorption of vitamins and minerals, conversely, how these nutrients impact gut microbiome. It goes on to discuss the possibilities of using individualised microbiome-based therapies for shortages of micronutrients and general benefits for health.

KEYWORDS

Absorption, Biosynthesis, Deficiency, Gut Microbiome, Micronutrients, Minerals, Vitamins

1. INTRODUCTION

Food digestion is highly pertinent for a healthy and nutritional condition of health. In the context of meeting the increasing need of the food in third-world countries, one needs to look at it more deeply from the viewpoint of availability and nutritional value of foodstuffs as well as the bioavailability of nutrients in the gut during its digestion. In the absence of absorption of nutrients, they assume no nutritional significance. The rate of nutrient release and uptake is equally as important as its quantity released from food. With many developed countries becoming older in terms of population dynamics, there has been a shift in new nutrition needs for that particular age group. Specifically, it is now evident that older adults will need to consume an adequate amount of protein throughout their day, at fairly frequent points in time in order to prevent the loss of muscular tissue (Paddon et al; 2009). It is obvious in the processing of modern processed foods but also in crop and animal production for whole foods and food fractions that digestion can play a determining role in the food. As put by Norton et al. : 'All foods undergo a common unit operation, the gastrointestinal tract, yet it remains the most under-studied and least understood of all food processes.". Tomorrow's foods have to be understood just like any other process that takes place internally in the body.

2. HUMAN DIGESTION – AN OVERVIEW OF THE PROCESS

The human digestive system can be thought of as consisting of four distinct sub-processes that occur in sequential stages, each with complex controls that regulate the movement of digesta from one stage to the next. For man, these stages may be considered as being: mouth (oral processing), stomach (gastric processing), small intestine (intestinal processing), and large intestine or colon (fermentation). A final important note is that all of the following processes are strictly sequential, without any reversal or overlap. The overall process is schematically summarized in Figure 1, and conditions for each step are described in Table 1. Additionally, it is assumed that all processes are at a temperature close to 37°C and in a predominantly aqueous medium.

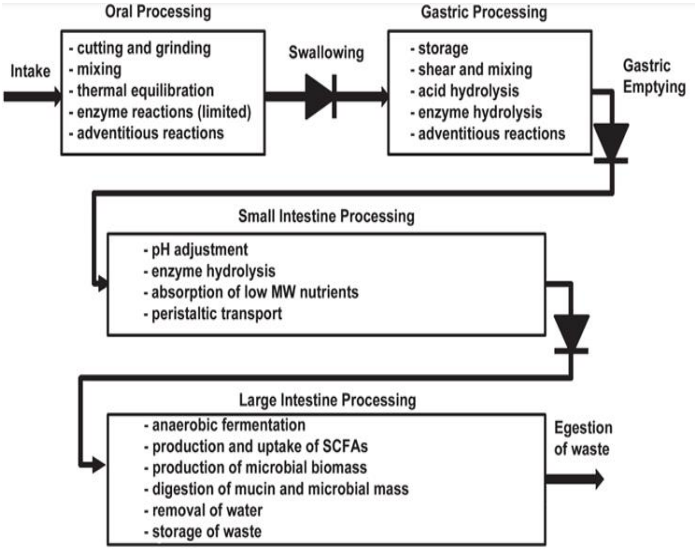

Figure 1: Overview of digestion as a process

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Table 1: General conditions found in each of the four main processes of the digestive tract

Table 1. General conditions found in each of the four main processes of the digestive tract

Process	pH	Redox potential (mV)	Residence/transit time	Comment	References
Mouth	Neutral	–	10–100 s	pH may be modified by food	–
Stomach	2	+200	1–2 h	See discussion below re pH and emptying time	3,4
Small intestine	7–8	−65 to −200	3–4 h	–	4,5
Colon	5–8	−400	24–48 h	Transit time varies widely between individuals. Acid production offset by secretion of bicarbonate in the ascending colon	4,6

2.1 Oral Processing

It happens first in the oral cavity. In this, cutting and grinding by the teeth, squeezing and mixing by the tongue and cheeks take place; later on, being uniformly mixed with saliva helps it reach body temperature and blend with other constituents of the meal. During this stage, the food is also sampled. Saliva is nearly neutral in pH. It contains an enzyme salivary amylase. This enzyme degrades starch into glucose. Saliva also contains mucins that constitute a group of glycoproteins and are important for creating cohesive bolus and ease of swallowing. These mucins contribute to viscosity, cohesion, and lubrication to facilitate the easy passage of food through the gut. When chews are sufficiently broken down and mixed with saliva, they are swallowed to complete this process. This oral processing can be considered to be a sequence of small-scale operations, with each intake of a mouthful as the input and subsequent swallowing as the output, taking place over quite a short period until a meal is completed. In this process, different food components can be swallowed and will be mixed either in the mouth, depending on eating patterns or in the stomach.

2.2 Gastric Processing

Swallowed food goes down the oesophagus and to the stomach, where it accumulates. The stomach is highly acidic, and its pH is typically about 2 due to hydrochloric acid produced by cells in the gastric wall. A good distension capacity exists in the fundus, which is the upper part of the stomach, allowing food stuffs to be stored during digestion. However, it is relatively separated from the antrum and the rest of the body. Particular antrum with the pylorus are known for vigorous contractions that are said to be mechanistically disruptive to the food structure with a contribution to the mixing of the stomach contents. Two digestive enzymes, pepsin and gastric lipase, are secreted into the stomach lumen to break down proteins and fats, respectively. Salivary amylase continues its action on carbohydrates in the stomach, but only if the mixing rate is appropriate and acid production acceptable. The pyloric sphincter releases the Digesta to continue its way to the small intestine, with the process of stomach emptying controlled by various factors, at least some of which are not well understood. One of the most important features of gastric emptying is that it controls the size of particles; this is often referred to as 'particle sieving', and normally particles of more than 1-2 mm are not left the stomach until it has been entirely emptied. This is significant, since the stomach is the only part of the gastrointestinal tract with a mechanical function which could potentially fragment particles. Gastric emptying starts as early as a few minutes after ingestion. It steadily takes a few hours for emptying after a meal (Minderhoud et al; 2004).

2.3 Intestinal Processing

The small intestine is thus divided into three parts which are; the duodenum, the jejunum, and the ileum. The first 30 cm of the small intestine functions as an important passage to assist in the conversion of the digesta from an acidic to a neutral pH environment. Here pancreatin-released hydrolytic enzymes from the pancreas initiate the process of breaking down proteins, fats, and carbohydrates. Besides, the pancreas brings bicarbonate to neutralize the pH and create an ideal environment for such enzymes. There is also incorporation of bile acids from the duct of the gall bladder that emulsify fats and break them down by the pancreatic lipase. The ileum and jejunum act as reactors of digestive enzymes and absorb tiny molecules because of their high surface area.

The digestive tract is the largest organ exposed to the outer environment and has an absorptive area of 30-35 m^2; its surface includes that of the small intestine (Helander et al; 2014). The intestines have a very folded surface covered with much villi and microvilli, in total increasing the surface up to 60-120 times. The products of hydrolysis-basically amino acids, small oligopeptides and mono- and disaccharides-compete with the rate of movings through the small intestine for passing to the surface of absorption, and the products of hydrolysis by bacteria of the colon are eaten up, if they are not absorbed by the digestive tract.

The bolus of food passes from the distal end of the small intestine to the colon through the ileo-caecal junction. The ileo-caecal valve, also called the valve of Bauhin, intermittently opens to allow digested substances to pass through but remains mostly in a closed condition. Its main function is to prevent backflow of the contents of the colon through the ileum and to prevent the digesta from the ileum from flowing down to the caecum in excess.

3. Changes in Food Nutritional Components During Gastrointestinal Digestion

The speed and site of food digestion in the mouth, oesophagus, stomach, and duodenum-the upper gastrointestinal tract -have a very significant impact on postprandial metabolism and overall human health (Lehmann and Robin, 2007; Zhang and Hamaker, 2009; Raigond et al., 2015; Miao et al., 2015). For example, if starch digestion is slow enough to allow leftover starch to enter the large intestine, SCFAs are created as a byproduct during fermentation. The three main SCFAs are butyrate, propionate, and acetate. Butyrate is especially essential since it can energize colonocytes and may even protect them from colorectal cancer (Conlon et al., 2012). Gastric emptying is slowed while GLP-1 and peptide YY (PYY) levels rise as a result of starch stimulation of the ileum or colon, causing the stomach to empty slowly and providing a sense of satiety via gut-brain feedback (Hamaker et al., 2013). On the other hand, the duodenum breaks down starch quickly after food intake, resulting in a substantial amount of glucose absorption in a short period of time and a spike in insulin and glucose levels in humans. This raises the risk of insulin resistance and type 2 diabetes. For human health, that starch should thus be slowly and sustainably digested-that is, fermented in the large intestine and digested in the lower sections of the small intestine.

3.1 Digestion and Absorption of Carbohydrates

Most Americans consume simple sugars consisting of glucose and fructose, disaccharides containing lactose and sucrose, and complex carbohydrates which consist of starch and glycogen. However, the carbohydrates account for 40–45% of the total daily calories that people consume; the remaining 50–60% account for plant starches (Lieberman and Marks, 2009). Salivary α-amylase facilitates digestion in the mouth for complex carbohydrates. Salivary and pancreatic α-amylases are endosaccharidases that break internal α-1,4 glycosidic connections (Devlin, 2006). They show virtually no activity on α-1,4 glucose linkages or α-1,6 glycosidic bonds at endpoints or branch points of branches. Both the amylases are almost 94% homogenous concerning amino acid sequences and come out in their active form (Binder and Reuben, 2009). Salivary α-amylase will survive in the stomach only if not exposed to acid; it is inactivated by acid pH. Salivary α-amylase can therefore break complex carbohydrates into smaller subcomponents and entrust those to be exposed to stomach acid in big lumps of food. Thus, up to 30-40% of complex carbs may thus be digested before they reach the small intestine. The other name for the hepatopancreatic sphincter is the Oddi sphincter. Pancreatic juice is allowed to flow into small intestine where its high level of concentration of bicarbonate begins to neutralize the acidic juice of stomach. Pancreas α-amylase breaks down complex carbohydrates into maltose, trisaccharides, larger oligosaccharides, and α-limit dextrins with branch points (Lieberman and Marks, 2009). In the event that α-amylase hydrolyses starch, di-, tri- and oligosaccharides are produced, which should be absorbed through further digestion to allow the release of the monosaccharide's breakdown products. These starch hydrolysis products have to be further broken down by membrane-spanning disaccharidases located on the plasma membranes of the brush borders of intestinal epithelial cells, called enterocytes (Binder and Reuben., 2009).

3.2 Digestion and Absorption of Proteins

In the stomach, ingested proteins or polypeptides are broken down by the action of the protease pepsin. Pepsinogen is the larger inactive enzyme released by the major cells of the stomach mucosa. Once activated by gastric acid (HCl), which is released by parietal cells, the pepsinogen splits and yields active pepsin in the stomach. In addition to protein denaturation, gastric acid partially unwinds them for proteases to break through their peptide bonds. Smaller polypeptides are produced in the stomach when the stomach enzyme pepsin, a type of endopeptidase initiates hydrolysis of proteins at different cleavage sites (Devlin, 2006). Once the partially digested food, known as chyme enters the small intestine, pancreatic protease enzymes and pancreatic bicarbonate are released through the hepatopancreatic sphincter. The bicarbonate elevates the pH to a degree that pancreatic proteases can function, which begins to neutralize stomach acid. Since all pancreatic proteases must be prevented from becoming active in order to avoid pancreatitis, they are secreted as zymogens. The zymogen trypsinogen is converted to trypsin by enteropeptidase (formerly called enterokinase), which is a jejunal brush-border enzyme that is activated by bile salts. The other zymogens are broken down into active forms by trypsin. Pancreatic proteases, which include trypsin, chymotrypsin, elastase, and carboxypeptidases, break down polypeptides into oligopeptides and amino acids (Lieberman and Marks.,2009).

Table 2: Characteristics of gastric, intestinal, and pancreatic peptidases

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Enzyme	Activators	Action	Cleavage Points	Products
Pepsin	Autoactivation	Endopeptidase	Tyr, Phe, Leu, and Asp	Large peptide fragments and free amino acids
Trypsin	Enteropeptidase and trypsin	Endopeptidase	Arg and Lys	Oligopeptides (2-6 amino acids)
Chymotrypsin	Trypsin	Endopeptidase	Tyr, Trp, Phe, Met, and Leu	Oligopeptides (2-6 amino acids)
Elastase	Trypsin	Endopeptidase	Ala, Gly, and Ser	Oligopeptides (2-6 amino acids)
Carboxypeptidase A	Trypsin	Exopeptidase	Carboxy-terminus Val, Leu, Ile, and Ala	Free amino acids
Carboxypeptidase B	Trypsin	Exopeptidase	Carboxy-terminus Arg and Lys	Free amino acids
Aminopeptidases		Exopeptidase	Amino terminus	Free amino acids

Modified from references: (Binder, 2009; Devlin, 2006; Aronson et al., 2003)

Exopeptidases assail the oligopeptides that are left after the action of these endopeptidases, cutting one amino acid at a time off one or both ends of the chain. The carboxypeptidases remove amino acids from the carboxyl ends of peptide chains (carboxy terminus), with carboxypeptidase A specifically releasing valine, leucine, isoleucine, and alanine and carboxypeptidase B releasing arginine and lysine (Devlin., 2006). The digestion of polypeptides and proteins by proteases yields 30% free amino acids and 70% oligopeptides (2-8 amino acids) (Binder and Reuben., 2009).

3.3 Digestion and absorption of Lipids

Lipid digestion may be initiated in the mouth by release of lingual lipase from the tongue glands, and further continued in the stomach from the release of gastric lipase and lingual lipase from the main cells. However, only 15% of fat digestion occurs by the time food leaves the stomach, hence that in adults most fat enters the duodenum intact (Binder and Reuben, 2009). Bile is released when there is fat in the duodenum as it stimulates the gallbladder, the pancreatic enzymes are produced, and the hepatopancreatic sphincter relaxes. The hepatopancreatic sphincter of the upper duodenum relaxes to allow the passage of bile and pancreatic enzymes into the lumen of the small intestine. Cooking enhances the emulsification of ingested fat that is chews afterwards and finally leads to the digestive system with churning and peristalsis in the stomach. Lipase from the stomach guts the fatty acids 15-20%. The hydrolysis, however, is only initiated in the duodenum and completed by pancreatic juice lipases (Lowe, 2002). Bile salts, phospholipids, and cholesterol coat the dispersed lipid particles so that they cannot collect again, and therefore stabilize the emulsion (Binder and Reuben, 2009). The activity of digestive lipases is also increased by the emulsification of dietary fat into an emulsion of small oil droplets since lipases have been selected to be more active at oil-water interfaces (Binder and Reuben, 2009). Because of their larger surface area, smaller fat globules are more accessible to active pancreatic enzymes to break them down. The emulsion droplets from the stomach, which contains nearly all the food triglycerides and diglycerides, is covered by polar lipids, phospholipids, fatty acids, cholesterol, triglycerides, denatured dietary proteins, dietary oligosaccharides, and bile salts in the duodenum (Lowe, 2002). Lipolysis occurs from the outside in, and as products are formed and broken down, the interface changes. Emulsion droplets break down into multilamellar liquid crystals, which, in turn, are transformed by bile salts into unilamellar vesicles and mixed micelles by adding more bile salts (Binder and Reuben, 2009). Although pancreatic lipase is secreted in an active state, pancreatic colipase is required to further the digestion process. Pancreatic colipase is activated by trypsin, which is released as procolipase. It has been postulated that lipase and dietary fat are complexed by colipase, thus allowing the triglyceride to access the active site of the lipase enzyme for hydrolysis (Lowe, 2002). Colipase also prevents inactivation of lipase caused by bile salt. Positions 1 and 3 of the glycerol molecule are hydrolyzed by pancreatic lipase, which produces free fatty acids and a 2-monoglyceride, also known as monoacylglyceride. Similarly, phospholipase A2 (which is secreted as prophospholipase A2) hydrolyzes dietary phospholipids into a free fatty acid and a lysophospholipid, whereas carboxyl ester hydrolase, also known as pancreatic esterase, cholesterol esterase, or lysophospholipase, removes fatty acids from dietary cholesterol. Pancreatic lipase/colipase typically breaks down the triglycerides in the upper part of the jejunum (Iqbal and Hussain., 2009). Food composition and structure have a major impact on how well-functioning and nutritious they are throughout digestion. (Bornhorst, 2017; Mackie, 2017; Dupont et al., 2018; Bornhorst and Singh, 2012, 2013; Bornhorst et al., 2014). It is during the digestive process that the food matrix influences how nutrients are subsequently freed and delivered to their locations within the body. Therefore, understanding the change mechanisms regulating how nutrients that are released from the diet during the digestion process might work toward the best health outcome is very crucial. The mechanism of breakdown varies with every meal and depends on the original food structure and how it changes during digestion. Many food disintegrations occur in the mouth, though some also result from passage through the gastrointestinal tract, which especially the stomach accounts for (Bornhorst and Singh, 2013; Bornhorst et al., 2013; Drechsler and Ferrua, 2016). The way in which foods disintegrate, wear away, and dissolve in the digestive system determines the effects that the consumed foods have on human health. Two mechanisms break down food: abrasion (surface erosion triggered by shear stress) and fragmentation (cleavage into smaller fragments). Researchers find two primary paths of food breakdown (Brandstaeter et al., 2019).

Meal characteristics like composition, amount, texture, structure, and viscosity, as well as physiological conditions in the digestive system like pH, temperature, and enzymes, affect the kinetics of food disintegration (Kong and Singh, 2008a, Kong and Singh, 2008b; 2009; 2010; Ferrua and Singh, 2010, Ferrua and Singh, 2011; Ferrua et al., 2011; Bornhorst et al., 2015; Drechsler and Ferrua, 2016; Mulet-Cabero et al., 2019).

4. Mechanisms of Digestive Processes Affecting Food Nutrition

Food processing in the digestive tract- The human GIT is basically an open-ended tube that runs through the ventral cavity of the body. The system includes the oral cavity, the esophagus, the stomach, the small intestine which also subdivides into duodenum, jejunum, and ileum, the large intestine subdivided further into ascending, transverse, and descending colon and rectum with anus as the final part. The GIT carries out the two motor functions: mixing and pushing actions. Mixing movements occur

when smooth muscles contract rhythmically in small parts of the tract. Peristalsis is a wave-like action generated by contraction behind food to allow it to pass to the following section of the digestive tract.

As food travels down the GIT, it mixes with digestive juices and food structures or matrices break down while large molecules are hydrolysed. The smaller intestine absorbs tiny molecules and nutrients directly into the bloodstream for delivery to the rest of the body.

4.1 Oral processing and food structure

The mouth cavity is the first chamber of the gastrointestinal tract, where food undergoes several physical and biochemical processes such as mechanical breakdown, temperature, dilution, pH, enzymes, salts, and mucus (Foegeding et al., 2011; Sarkar et al., 2009). Mastication breaks down food structures into lubricating masses. Saliva lubricates by softening the fragments of food and shaping them into a coherent bolus (Foegeding et al., 2011). Mechanical and structural properties in the oral cavity determine food fragmentation (Agrawal et al., 1997, Lucas et al., 2002). Food hardness or resistance to being deformed persistently is a basic physical characteristic to be observed before the bite. Food fracturing and fracture influence the production of the bolus during mastication. Additionally, thermal features also influence the food breakdown. Chocolate is hard while initially in the mouth then breaks into fine particles upon chewing and dissolves into a viscous semisolid bolus (Bouzas and Brown).

4.2 Gastric processing and food structure

This involves reactions of the bolus with the gastric juice, including particle swelling, diffusion of the gastric juice, acid hydrolysis, enzymatic hydrolysis, and mechanical shearing. The antrum of the stomach combines mechanical elements such as antral contractions with chemical elements of acid and pepsin in grounding and separating the food particles. Before entering the pyloric aperture, the average particle size is reduced to less than 1-2 mm. The disintegration rate of food constituents, depending on structure and properties, is significant for gastric emptying. The acidic environment of the stomach does not break down protein in foodstuffs, whereas pectin, a main component of cell walls in plants, is partially gelatinized during the gastric phase (Kong and Singh., 2009; Tydeman et al., 2010). However, the role of acid and pepsin depends on diffusion of gastric juice to food particles (within the bolus), which is determined by structural as well as material qualities of the meal. Ion diffusion into food particles, including Na+, Cl+, and H+, significantly alters their physicochemical properties. On the other hand, H+ transport leads to ionization of NH2+ to NH3+, which tends to increase charges and thus electrostatic repulsion and, consequently, the relaxation of the food network. Material properties of food thus ultimately define the velocity of disintegration in the stomach.

5. Gut Microbiome- Micronutrient Interactions

Since the microbes take micronutrients to produce and to promote their growth and proper functioning, it is not very surprising that intake of these micronutrients would influence composition and functional organization within the gut microbiome. Vitamin supplements: Vitamins B, C, D, and E for example have been found to significantly affect the kind of microbiomes. This is through ensuring that the micro-multiplication as well as colonization of the intestinal mucosa occurs in such genera as Bifidobacterium, Lactobacillus, and Roseburia (Lv et al.,2016; Li and Somerset.,2018; Kanhere et al., 2018; Degnan et al., 2014). Minerals include calcium, iron, zinc, magnesium, and phosphorus, all of which have been predisposed to affect the gut flora of human beings (Bielik and Kolisek., 2021; Yang et al., 2020). High calcium intake was associated with a higher proportion of Clostridium cluster XVIII in men, while iron supplementation was associated with a decrease in Bifidobacterium and an increase in Lactobacillus species among children. In addition, phosphorous supplementation was associated with an increase in stool microbial diversity and SCFAs. The intestinal microbial ecosystem is very vital in influencing the absorption of such micronutrients as phosphorous and calcium and in the production of other essential vitamins, including vitamin K and the B water-soluble group.

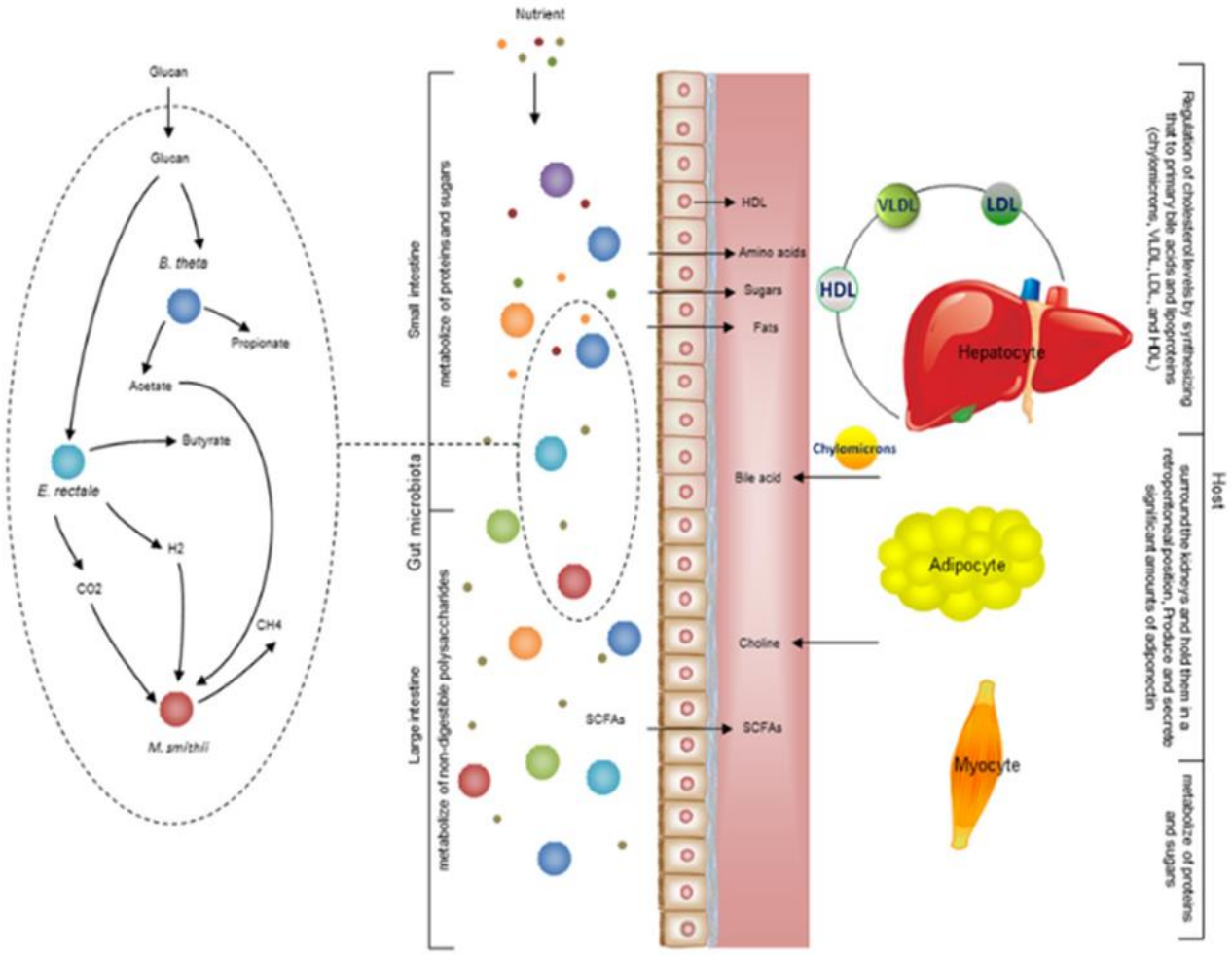

Figure 2: Elucidating the interactions between the human gut microbiota and its host through metabolic modeling - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Interaction-between-the-gut-microbiota-and-host-There-are-different-types-of-metabolic_fig4_262055779 [accessed 14 May, 2024].

Relationship between the host and intestinal bacteria. The bacteria in the gut ecosystem interact metabolically in a variety of ways. Three species make up this simplistic model community: B. thetaomicron and E. rectale eat oligo- and poly-saccharides, while M. smithii absorbs acetate and CO2 or formate. In this reduced community, the main interactions are with acetate, H2, and CO2. Three SCFAs—acetate, propionate, and butyrate—are the main byproducts. The majority of these metabolites are taken up by epithelial cells. Colocytes use butyrate as an energy source, while propionate and acetate are transported to the portal vein and then utilised by adipocytes and hepatocytes. The food passes through several parts of the intestine, where the micronutrients are progressively broken down. Host enzymes break down some carbs, proteins, and lipids, while the microbiota breaks down indigestible ones. This process originates predominantly in the stomach and continues extensively through the small and large intestine. The portal vein carries the available SCFAs to the liver. Because hepatocytes synthesise primary bile acids and lipoproteins, such as chylomicrons, very low-density lipoprotein (VLDL), low-density lipoprotein (LDL), and high-density lipoprotein (HDL), they regulate cholesterol levels. It is quite probable that the microbiome's synthesis of acetate and other chemicals has a significant influence on this control. Adipocytes and myocytes communicate with each other through the transfer of free fatty acids.

5.1 Minerals

Human gut microbiome harbors several bacteria that can influence the status of minerals in a host, both through the wide range of enzymes synthesized to break down minerals from dietary sources, and also by directly affecting the rate of absorption at the gastrointestinal level. Phytases are bacterial enzymes that degrade phytic acid in plant-based meals and mobilize available minerals, which include calcium, magnesium, iron, and phosphorus, from feedstuffs (Bohn et al., 2007). The microbial metabolites of the fermentation of polysaccharides - SCFAs - lower pH in the gastrointestinal system, thus increasing the calcium's solubility as well as its transepithelial transport as demonstrated in vitro using rat cecum and colon preparations (Mineo et al., 2001).Calcium and phosphate form amorphous complexes in the small intestine, allowing bile and fatty acids to interact with them (Van der Meer et al.,1997;Ditscheid et al., 2005) this way influencing the gut flora's composition (Ditscheid et al., 2005; Trautvetter et al., 2012). Zinc deficiency in vivo has been shown to affect the gut microbiome regarding its composition, thus resulting in a decrease of biodiversity, an increase of inflammatory markers, and impairment of the functional potential associated with gut-brain transmission (Sauer et al., 2019; Reed et al., 2015). Despite the low number of the estimated pediatric cohort, a subsequent clinical study by Ballini et al. emerged that supplementation with a synbiotic containing the probiotic species L. Such supplements include plantarum, Lactobacillus acidophilus, Bifidobacterium infantis, and Bifidobacterium lactis, that are used along with the prebiotic fructooligosaccharide, may be helpful for elevating blood zinc levels.

5.2 Vitamins

Many species of bacteria that are naturally well-suited to the human gastrointestinal niche, such as Bifidobacterium, Bacteroidetes, and Enterococcus, synthesize vitamin K and group B vitamins, and it is also known that their water-soluble derivatives are produced. Magnusdóttir et al., computationally investigated the ability of 256 common human intestinal commensals to synthesize biotin, cobalamin, folic acid, niacin, pantothenic acid, pyridoxine, riboflavin, and thiamine (Magnusdottir et al., 2015). There is also evidence of dietary B vitamin supplementation that has been associated with changes in gut microbiome diversity and composition. For example, vitamin B3 supplementation increased Bacteroidetes, improved markers of metabolic inflammation and insulin sensitivity (Fangmann et al., 2018). Subramanian et al. demonstrated that intestinal microbiota decreases the absorption of vitamin C through down-regulation of sodium-dependent transporters using the lipopolysaccharide-treated intestinal enteroids model (Subramanian et al.,2018).On the other hand, in comparison to placebo, vitamin C treatment was demonstrated to significantly increase microbial ecosystem diversification and relative abundance of Collinsella and fecal level of SCFAs, especially butyrate and propionate (Pham et al., 2021). Intake of vitamin E was reported to be positively related to increasing production of SCFAs, besides certain beneficial bacteria such as Akkermansia, Lactobacillus, Bifidobacterium, and Faecalibacterium (Choi et al., 2020).

5.3 Techniques to monitor the nutritional component changes in the gastrointestinal digestion

For example, the traditional approaches to in vivo studies of digestion often are invasive, using sensors to measure pH or gastric pressure or aspiration of stomach contents through a nasogastric tube. In consequence, digestive processes are often studied under controlled and simplified conditions using in vitro model systems (Reference Brodkorb, Egger, and Alminger7). This paper has described the enzymatic involvement in the modification of the chemical and physical properties of food structures during digestion. In this manner, ingestible devices, which may get samples or measurements could be a new way of counteracting that to some extent (Kozioleket al., 2015). As cited by van Duynhoven, Voda, Witek13 and Hatzakis14, NMR provides information of the state of water protons in food and has been used enormously as a characterization tool and quality control tool of processes in different food systems. This method measures digesta or stomach aspirates in vitro at low magnetic field strengths of about 0.5 T. In addition to the volume of fractions of stomach content, MRI will be able to detail gallbladder responses (see Marciani, Cox and Hoad, 2015), intestinal parameters such as small bowel water content and intestinal motility, and intra-gastric processes like phase separation and clot formation.

In vitro digestion of fish (Reference Nieva-Echevarría, Goicoechea and Guillén36, Reference Nieva-Echevarría, Goicoechea and Manzanos37), sunflower oil (Reference Nieva-Echevarría, Goicoechea and Manzanos38), and complex lipid mixtures (Reference Nieva-Echevarría, Goicoechea and Manzanos35) has been measured using NMR for lipid hydrolysis products, including diglycerides and fatty acids. NMR has been utilised to study protein hydrolysis in vitro in addition to lipid hydrolysis. Using an NMR spectrometer, Sundekilde et al. (Sundekilde, Jarno, and Eggers39) were able to track the real-time hydrolysis of animal proteins by enzymes.

6. Conclusion

Some of the ways in which the gut microbiota plays its role in the modulation of absorption, metabolism, and utilization of essential micronutrients are through biochemical interaction with human host essentials, as well as the production of metabolites or other substances which may enhance or inhibit their absorption, metabolism, and utilization. The diversity and composition of gut microbiota can influence the solubility and bioavailability of minerals such as calcium, magnesium, and iron and vitamins such as B vitamins and vitamin K. Other benefits of gut flora are its ability to ferment dietary fibers, followed by the production of short-chain fatty acids, with subsequent effects on nutrient absorption and nutritional status in general. Understanding this interplay provides insight into how dietary interventions and probiotics could be strategically used to optimize micronutrient status and alleviate deficiencies. Further research in future studies is required to study the mechanisms at which these interactions take place and may be used to enhance health outcomes in populations that are at risk from deficiencies of micronutrients. This understanding of gut-micronutrient relationships can reveal key insights to translate into better tailoring of nutrition strategies and therapeutic approaches to enhance nutritional health and well-being.

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