Evidence for Redefining Dietary Fiber

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Abstract

There are currently three macronutrients recognized within the field of dietetics due to their gram quantity intake and requirement for human health; this includes proteins, fats, and carbohydrates. Dietary Fiber, however, is not considered to be an independent macronutrient despite its gram quantity intake and requirement for human health. Additionally, Dietary Fiber is a net-zero energy yielding nutrient unlike other carbohydrates. Although Dietary Fiber should remain chemically categorized as a carbohydrate, for the purposes of dietetic prescription and education, Dietary Fiber should be redefined as the fourth macronutrient. This definition shift would illustrate both the importance and complexity of this macronutrient and may yield an increase in Dietary Fiber consumption and relevant research.

Keywords: Dietary fiber, Insoluble fiber, Soluble fiber, Functional fiber, Microbiome, Macronutrient

Introduction

Diet related preventable illnesses and mortalities are at an all-time high in the United States. Without meaningful trend regression, rates of obesity, heart disease, diabetes, and cancer will continue to increase (Hales et al., 2020; Wang et al., 2021; Zhao et al., 2020). The diet of Americans and other western countries is a large contributor to these health concerns. The "western diet" is a diet rich in processed foods and refined sugars while also being low in plant-based foods such as fruits, vegetables, whole grains, and legumes. The western diet is born out of perceived cost saving and convenience, which translates to a high consumption of fast food. According to a 2018 NCHS data brief, on any given day between 2013 and 2016, 36.6% of US adults consumed fast food (Fryar et al., 2018). Furthermore, between 2007 and 2010, adults consumed on average 11.3% of their total daily calories in fast food with obese Americans consuming the most at an average of 13.1%. This effects the younger generations the most, as individuals aged 20-39 who were underweight/normal weight consumed 13.5%, overweight individuals consumed 14.7%, and obese individuals consumed 18% of their total calories in fast food (Fryar & Ervin, 2013). The western diet has been linked to obesity, cancer, diabetes and prediabetes, osteoarthritis (OA), low-grade inflammation, antimicrobial resistance (AMR), coronary heart disease (CHD), hypertension, dyslipidemia, constipation, and dysbiosis (Anderson et al., 2009; Dai et al., 2017; Guan et al., 2021; Koç et al., 2020; Liu et al., 2021; Oliver et al., 2022; Stewart & Schroeder, 2013; Wang et al., 2021). Combating these preventable illnesses is multifactorial. Evidence suggests that one effective way is to increase Total Dietary Fiber (TDF) intake, a proposed dietary change that is convenient and affordable. Efforts to increase Dietary Fiber (DF) intake across the US however have occurred with no meaningful change. One study, which included over 48,000 women, found that 38 intensive behavioral education sessions across six years did not yield significant results. These education sessions were intended to decrease fat consumption to less than 20% of their total calories and to increase fruit and vegetable intake to five servings a day and increase grain intake to six servings a day. Results indicated an increase on average of 1.5g/day of TDF, showing that education alone may not be enough to increase national DF intake (Anderson et al., 2009).

After reviewing the history of DF, modern evidence, and recommendations, nutritionally redefining DF as the fourth macronutrient instead of its current definition as a subset of carbohydrate may be a necessary step in the future of dietetics. This is because DF is needed in gram quantities, is net-zero energy yielding, and confers specific and measurable health benefits separate from energy yielding carbohydrates. This change in categorization may increase DF consumption, research, and illustrate the importance of this macronutrient. It is important to note however that this proposal extends only to the field of dietetics and is not a claim that DF is not a carbohydrate, as such this change in categorization would only extend to organizations like the USDA, FDA, the Academy of Nutrition and Dietetics, and other nutrition related organizations.

Methodology

Using EBSCO, twenty-one publications were compiled. Information was carefully curated based on four criteria, 1.) provides an exact definition and/or classification of DF or macronutrient, 2.) provides current DF daily intake and/or recommended daily intake, 3.) provides function and/or effect DF has on the body, 4.) provides evidence that a change in the nutritional classification of DF would be beneficial.

Current knowledge

A History of Fiber

DF, an essential macronutrient for human health, has been an important component of our diet since our infancy as a species. Indeed, our ancestors consumed hefty amounts of DF during their hunter gatherer nomadic lifetime. It is estimated that ancient humans consumed between 77g/day and 120g/day of DF between 125,000 and 1,000,000 years ago, easily exceeding the consumption of modern humans by five to eight times the amount (Howarth et al., 2001; Koç et al., 2020). This was of course before the advent of modern science and medicine, as such early humanity did not know that this macronutrient was essential for their health. In fact, it was not until recently that DF was identified as an essential macronutrient. Approximately 2,300 years ago The Father of Medicine, Hippocrates, identified that whole grain bread was a healthy food and recommended it to his patients (Korczak & Slavin, 2020). This discovery of whole grains conferring health benefits was rediscovered twice more, firstly by W. K. Kellogg and C. W. Post during the beginnings of the cereal industry in the mid to late 1800s and then once more in the 1970s by Burkitt and Trowell who observed that common illnesses and diseases found in western populations were far less common in rural African populations that consumed higher amounts of carbohydrates and DF (Korczak & Slavin, 2020). Whole grains have since been defined by the American Association of Cereal Chemists as, “Whole grains shall consist of the intact, ground, cracked or flaked caryopsis, whose principal anatomical components – the starchy endosperm, germ and bran – are present in the same relative proportions as they exist in the intact caryopsis” (Stewart & Schroeder, 2013). More recently prebiotics were introduced as a concept in 1995 and were at the time defined as “nondigestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, thus improving host health", since then it has been redefined as "a non-digestible compound that, through its metabolization by microorganisms in the gut, modulates the composition and/or activity of the gut microbiota, thus conferring a beneficial physiologic effect on the host" (Korczak & Slavin, 2020).

Since its identification as a dietary nutrient, there have been continued debate on not only how to define DF but also how to chemically measure it; presenting numerous challenges when measuring both the TDF consumed in a population and the types of DF consumed in relation to each other (Korczak & Slavin, 2020). This is an important obstacle to overcome as the different types of DF confer different health benefits. Furthermore, there are also three other DF that have been identified. Soluble Fiber (SF), Insoluble Fiber (IF), and Functional Fiber (FF); formally Added Fiber (AF). Although the terms Soluble and Insoluble were recommended to be eliminated in 2001 by the IOM for more specific descriptors that would be used on individual compounds, such as viscosity and fermentability, it would appear that the terms are here to stay (Korczak & Slavin, 2020). The IOM later recommended redefining AF as FF, this recommendation was far more successful and now has become interchangeable with AF as well as isolated fiber (Korczak & Slavin, 2020).

Prior to 2001, defining and measuring DF was an even greater challenge than it is today. As identified by the IOM in their 2001 publication *Dietary reference intakes: Proposed definition of dietary fiber*, there were a total of eighteen definitions for DF between the years 1976 and 2000. All of which varied immensely in nomenclature and length as well as country of origin and organization. Additionally, there were a handful of definitions prior to 1976 that were built upon a definition proposed in 1929 by McCance and Lawrence (Institute of Medicine, 2001). In section IV of *Dietary reference intakes: Proposed definition of dietary fiber*, the IOM defines DF as follows, "Dietary Fiber consists of nondigestible carbohydrates and lignin that are intrinsic and intact in plants" and AF, now referred to as FF, as, "Added Fiber consists of isolated, nondigestible carbohydrates that have beneficial physiological effects in humans", finally they define

Total Fiber, or TDF, as, "the sum of Dietary Fiber and Added Fiber" (Institute of Medicine, 2001). Even though DF was identified as a nutrient of concern in 2005 by the Dietary Guidelines for Americans and has continued to fall well below every recommendation provided by health organizations internationally, DF deficiency is not treated with the same urgency as protein or lipid deficiency is often treated (Quagliani & Felt-Gunderson, 2015).

Recommendations

Although there are multiple recommendations for DF consumption, there are no recommendations that supersede another (Stewart & Schroeder, 2013). Current recommendations vary in the adequate daily consumption of DF. For instance, much like protein, carbohydrates, and lipids, there are gram quantity recommendations that vary based on age, calorie consumption, and biological sex. These recommendations include the Age +5 rule, which may be increased to Age +10 safely in some instances, which was introduced in a 1995 report on the importance of DF consumption in childhood and has since become a common recommendation method that follows the child up from the age of 2 until the age of 20, where their adult consumption is between 25g/day and 35g/day (Korczak & Slavin, 2020; Stewart & Schroeder, 2013). The American Academy of Pediatrics recommends that children aged 1-18 consume 4.5g/day up to 34.5g/day, scaling with the age of the child (Stewart & Schroeder, 2013). There are also recommendations for children between the ages of 6 and 12 months where DF consumption should be increased to 5g/day after breast feeding has either ended or lessened (Stewart & Schroeder, 2013). Recommendations for adults, as well as children, may also come in the form of Adequate Intake or AI for short. AI is based on prospective cohort studies that examined DF intake and cardiovascular disease risk, or CVD risk, that found the minimum average intake of DF that protects against CVD was 14 grams of DF per 1,000 kilocalories per day (Korczak & Slavin, 2020).

There are a few important concerns to note with DF intake which can disproportionately affect children and other individuals who are at risk of malnutrition and nutrient absorption, such as those with gastrointestinal disease and illness, connective tissue disorders, or the elderly. Firstly, DF will increase water retention in the colon causing softer and bulkier stools; as such it is imperative that with the increase to adequate DF intake that water intake also increases proportionally, this will roughly come out to 1 liter of water per 10 grams of DF with slight variation based on age and sex (Anderson et al., 2009). Secondly, excessive DF intake should be avoided. The likelihood of this occurring is more prevalent in children but may be seen in adults with poor nutrient absorption or the elderly. Excessive DF intake may negatively affect energy and nutrient intake through an increase in fecal energy loss, reduced energy intake from satiety, and a decrease in the bioavailability of minerals; more specifically iron, as some sources of DF are rich in phytates and oxalates (Stewart & Schroeder, 2013). Finally, a sudden increase in DF intake, particularly in the form of SF, may induce symptoms of irritable bowel syndrome even in those who consume it strategically; these symptoms include abdominal distension, flatulence, constipation, and diarrhea (Guan et al., 2021).

Achieving adequate TDF intake may be difficult for many people, as evidenced by the current daily intake of many western countries. Furthermore, when DF is linked to caloric intake it is difficult to achieve the daily DF recommendation even when consuming nutrient-dense food choices with the current recommendations of plant-based food servings (Korczak & Slavin, 2020). Thus, the recommended serving sizes for fruits, vegetables, leafy greens, whole grains, and legumes should be increased; or more realistically, the average consumer should be educated that the USDA Guidelines for Americans is actually the minimum serving size for health and should strive to consume more than the recommended amounts of plant-based foods.

Further difficulties arise when marketing confusion comes into play, not because the average person is nutrition label illiterate, but because of misleading phrases used by companies to illustrate their product as being healthful. For example, what is “a good source of fiber”? In the US a “good source of fiber” is required to have at minimum 2.5 grams of DF per serving and a “high source of fiber” must contain at minimum 5 grams of DF; whereas in in EU a “high source of fiber” must contain at least 6 grams of DF per serving and a “source of fiber” must contain at least 3 grams of DF per serving (Koç et al., 2020).

Although seemingly difficult, it is certainly possible to reach the adequate intake of TDF in a day. This can be achieved through small changes in the diet such as increasing the servings of fruits and vegetables you consume in a day or consuming more whole grains. In fact, grain-based foods are some of the most common foods eaten internationally in the form of breads, pastas, confectionaries, and cereals. Despite this, whole grains are adequately consumed by only 7.6% of the global population (Williams et al., 2020). More specifically, surveys indicate that 17% of adults in the UK meet the recommended amount of whole grain servings in a day and only 8% of US adults meet these recommendations (Williams et al., 2020). The current recommendations for whole grain consumption are that one should consume at least half of all grains as whole grains and make a conscious effort to slowly replace any refined grain consumed with whole grains, thus increasing TDF intake (Stewart & Schroeder, 2013). Given that the current USDA Guideline recommendations for whole grains is just three servings, or three ounces, a day; this can easily be achieved by eating just three slices of whole wheat toast in a single day (Stewart & Schroeder, 2013). Further marketing confusion can be seen in the breakfast cereal aisle of many grocery stores where 34% of all breakfast cereals that identify themselves to the consumer as being whole grain do not even meet the requirements of being labeled as a “good source of fiber” which is a mere 2.5 grams of fiber per serving (Quagliani & Felt-Gunderson, 2015).

Consumption

Historically, DF consumption is at the lowest it has ever been for our species. Equally, CVD, obesity, and several other forms of preventable illness associated with diet are at its highest and show no signs of decreasing (Hales et al., 2020). These health concerns are seen both nationally and internationally with the US only consuming an average of 18g/day of DF for adults, the EU consuming between 16-28g/day, and the UK consuming an average of 19g/day (Koç et al., 2020). Sadly, many census organizations around the globe do not account for types of DF consumed, only TDF. This means that it is unknown how much IF, SF, and FF are being consumed by the public and in what ratio they are being consumed in relation to each other (Koç, et al., 2020). Only 5% of US citizens report consuming the recommended amount of DF a day despite consumer research reports which show that most people in the US both believe that they consume enough DF and that they understand the health benefits of DF (Quagliani & Felt-Gunderson, 2015).

Health Effects

As stated previously, DF in all its forms is an essential macronutrient for health. Although there are many compounds under the umbrella of DF, all conferring different health benefits, they all share one commonality. DFs are net-zero energy yielding compounds that confer specific and measurable beneficial health effects in humans. Most, but not all, of these compounds are identified as non-starch polysaccharides (Howarth et al., 2001). Compounds that are considered DFs that are not non-starch polysaccharides include lignin, inulin, resistant starches, oligosaccharides, and chitin; though there may be more introduced as DF is continually researched (Anderson et al., 2009; Korczak & Slavin, 2020).

DF and its effect on the human body have been well researched and documented, when consumed at adequate levels DF reduces the incidence of the following illnesses and diseases; CHD, stroke, hypertension, diabetes, obesity, certain gastrointestinal disorders, dysbiosis, hyperlipidemia, metabolic syndrome, select forms of cancer, and liver disease (Anderson et al., 2009; Guan et al., 2021; Koç et al., 2020; Liu et al., 2021). Adequate DF consumption also improves serum lipid concentrations, lowers blood pressure, improves blood glucose control in diabetics, promotes regular bowel movements, aids in weight loss, improves immune function, and acts as a source of carbon and energy for the human microbiota found within the colon (Anderson et al., 2009; Guan et al., 2021). SF, and some IF to an extent, are known to create a viscous gel matrix which not only protects the colon from physical contact with carcinogenic compounds but also delays gastric emptying causing increased satiety and increasing the total time of nutrient absorption (Anderson et al., 2009; Liu et al., 2021). In turn, IF is known to both dilute the carcinogenic and pro-carcinogenic compounds in the colon while also speeding transit time in the colon, thus creating a two pronged approach in protecting the body from harmful substances both carcinogenic and non-carcinogenic (Liu et al., 2021).

Gut Microbiome

It is now common knowledge that humans share a symbiotic relationship with our microbiota, sometimes referred to as a microbiome, virtual organ, or even the forgotten organ. Only recently have we begun to understand the composition and function of our microbiome, with new discoveries being made frequently. For the microbiota in our colon to survive it must be "fed" DF. This is where the fermentability of certain DFs becomes essential. DFs identified as being SF, many of which have been further identified as being prebiotics, are the primary source of carbon and energy for our gut microbiota. Although IF can also be fermented in our colon, SF is exceedingly more beneficial for microbiota health due to its high fermentation efficiency (Guan et al., 2021).

The microbiome located in our colon is home to roughly thirty-seven trillion microorganisms, though this will vary from person to person. The denizens of our colon are made up of eukaryotes, archaea, bacteria, and viruses. The most prevalent of them are bacteria from the *Bacteroidetes*, *Firmicutes*, *Actinobacteria*, *Verrucomicrobia*, and *Proteobacteria* phyla. Our exact microbiome composition is directly influenced by age, environment, genetics, and diet. Diet is predicted to account for over 50% of the variation in our microbiome (Williams et al., 2020).

Although microbiologists have yet to conclusively define what a healthy microbiome is and how it should be composed, they have identified that microorganism diversity is beneficial to the host. These beneficial microorganisms will ferment the DF consumed creating SCFAs (Williams et al., 2020). These SCFAs, known as metabolites, have been identified as being beneficial to the host as well. In particular, the SCFAs acetate, propionate, and butyrate have many beneficial effects and are produced in the highest quantities. Acetate, being the most produced, serves as a good substrate for glial monocarboxylate transporter 1 (MCT1) and neuronal MCT2, and a poor substrate for MCT4 (Jha & Morrison, 2018). Acetate also serves as a ligand for G protein-coupled receptor 41 (GPR41) and GPR43 (Koç et al., 2020). Propionate serves as a gluconeogenic substrate and acts as ligand for GPR41 and GPR43. Butyrate acts as a ligand for GPR41, GPR43, and GPR109A in addition to being an energy source to colon epithelial cells, known as colonocytes (Koç et al., 2020).

As discussed previously, the diets of many westernized countries have been largely industrialized and as a result are low in whole food consumption. In particular the chronically low consumption of DF has dealt a possibly fatal blow to many people's microbiome. The result of this damage is known as dysbiosis and it has severe consequences which may include CVD risk, obesity, type 2 diabetes, hypertension, chronic low-grade inflammation, inflammatory bowel disease, *Clostridium difficile* infection, increased risk of cancer, depression, Alzheimer's disease, and a compromised immune system (Koç et al., 2020). Dysbiosis is an imbalance of the microbiome either through the decrease or increase of select groups of microorganisms. As stated previously the microbiome is influenced predominantly by diet, so when someone's diet is deficient in DF for a prolonged period or even for a lifetime certain microorganisms will decrease in population or no longer be present in the gut. Most commonly the microorganisms that will have a significant decrease in abundance are the beneficial SCFA producing microbes, such as *Lactobacillus* spp. and *Bifidobacterium* spp. When this happens the now empty space is filled with other microorganisms such as potentially pathogenic microorganisms or microorganisms already found within the colon. For example, dysbiosis may occur when the ratio of *Firmicutes* and *Bacteroidetes* becomes too high. This high *F/B* ratio is positively correlated with obesity, type 2 diabetes, and hypertension. High consumption of DF has been found to prevent dysbiosis and treat it provided the dysbiosis is not severe. If an entire group of microorganisms is no longer present in the colon, it is impossible to restore them with DF consumption alone. This is expressed best in what is known as "responders" and "non-responders" wherein the inter-individual variation of the microbiome becomes so strong due to dysbiosis that in any group of people who suffer from dysbiosis, some will respond to increased TDF and begin fermenting the compounds into SCFAs and restore microorganism populations; while others will be non-responders and fail to ferment significant amounts of DF due to the reduced or absent population of SCFA producing microorganisms (Koç et al., 2020).

Although it is impossible to take a fresh sample of the microbiome of our ancestors during the beginnings of agriculture, a look to those left who have not yet adopted the diet and lifestyle of many westernized countries can provide clues to prior intake. There are rural village inhabitants of Burkina Faso, a West African country, who consume a diet high in DF like the diet that early agriculturalists would have consumed before the advent of industrialism. When comparing the microbiomes of children in these rural villages with the microbiomes of Italian children consuming a highly westernized diet, the children of Burkina Faso's microbiome were found to have a significantly higher biodiversity. Furthermore, there were two genera of *Bacteroidetes* found within the microbiomes of the Burkina Faso children that were not found in the Italian children, *Xylanibacter* and *Prevotella*, that are responsible for metabolizing cellulose and xylan. In contrast the Italian children's microbiomes had significantly higher concentrations of the potentially pathogenic bacteria *Shigella* and *Escherichia*. The Burkina Faso children also had significantly higher amounts of SCFAs being produced (Koç et al., 2020).

Equally, fresh microbiome samples of our even earlier ancestors who lived a largely nomadic hunter-gatherer lifestyle are also unavailable. Thankfully, there are rare populations of people who still live this way and are largely welcoming towards researchers. One such group is the Hadza people of Tanzania who consume an entirely seasonal diet. They have a wet season between November and April and then a dry season between May and October; these seasons directly influence their food availability and therefore their microbiomes. During the dry season their consumption of wild game increases while the frequency of their berry and honey foraging decreases, the opposite occurs during their wet season where meat is less available, and berries and honey are more abundant. Throughout both seasons however they maintain a staple part of their diet, fiber-rich tubers and the edible parts and fruits of the baobab tree. As a result of their seasonally varied diet, the *Bacteroidetes* population decreases significantly during the wet season whereas the *Firmicutes* remain remarkably stable across all seasons (Koç et al., 2020). This is hypothesized to be due to the Hadza people's consumption of fiber-rich tubers and baobab. Astonishingly, some research has indicated that the Hadza people of Tanzania present no evidence of CVD risk factors and even that there were low reports of infectious diseases, nutritional deficiencies, and metabolic diseases compared to groups who had settled in the surrounding regions. Although it is difficult to measure the exact amount of DF the Hadza people consume, it is predicted that their intakes are upwards of 100g/day or more depending on the season (Koç et al., 2020).

Constipation

In adulthood constipation is commonly defined as, "three or less bowel movements per week." There are two types of constipation, Organic and Functional. Organic constipation is due to pathological conditions such as anatomical malformations, abnormal abdominal musculature, connective tissue disorders, metabolic or gastrointestinal disorders, neuropathic disorders, and intestinal or nerve disorders. Functional constipation, the most common form, may be due to situational, psychological, developmental, or dietary causes. Dietary factors are one of the most common reasons for Functional constipation in both childhood and adulthood. These factors include an absence, or deficiency, in IF and low fluid intake (Stewart & Schroeder, 2013). Additionally, constipation can be either chronic or acute. Acute constipation may happen suddenly and alleviate suddenly. Often, acute constipation is due to a sudden change in diet, routine, or stress. Chronic constipation however is long term, one study found that 45% of people with chronic constipation would continue to report symptoms of constipation for at least 5 years (Rao et al., 2016). It is estimated that the median prevalence of constipation is 16% in the US, with a 33.5% prevalence of constipation in adults aged 60-101 years. Minority groups, women, and institutionalized elderly are at a higher risk of developing constipation (Rao et al., 2016). In children, it is estimated that 1.1% of all children aged 0-18 years suffer from constipation, with ages 0-9 being the most affected. Given, however, that constipation affects children and elderly more often it is thought that current predictions vastly underestimate the prevalence of constipation in children (Stewart & Schroeder, 2013). This may be due to a higher occurrence of acute constipation in children, skewing reports that only factor for present constipation.

There are multiple treatments for constipation, both acute and chronic, such as laxatives, addressing medications of concern that may be causing the constipation, medications formulated to combat constipation, and increasing fluid and DF intake. DF supplements may be used, but the use of whole foods appears to be more effective (Rao et al., 2016). DF however is unique to the other treatments listed, as it is also a preventive measure. For example, children that do not meet the Age +5 recommendation are more likely to experience constipation than children who meet the recommendation. Furthermore, chronically constipated children who increased their DF consumption by 9.5% (46.8% to 56.3%) experienced a significant decrease in clinical symptoms of constipation (Stewart & Schroeder, 2013).

The effect of constipation also contributes significantly to health care costs. It is estimated that in the US $821 million is spent on laxatives alone (Rao et al., 2016). Furthermore, approximately $12.7 billion in direct health care costs related to functional constipation could be saved if every adult in the US consumed an additional 9 grams of DF every day or $2 billion if only half of all adults increased their daily consumption by 3 grams (Quagliani & Felt-Gunderson, 2015).

Cardiovascular Health

Adequate daily intake of DF reduces the risk of developing CHD, stroke, peripheral vascular disease, and hypertension; increased DF intake also improves serum lipid concentrations (Anderson et al., 2009). It appears that the preventative measures of DF are dose dependent, as those that consumed the highest amount of DF have a 29% lower prevalence of CHD than those that consumed the lowest across seven cohort studies observing over 158,000 individuals. Furthermore, a higher intake of whole grains is associated with a 26% reduction in the prevalence of ischemic strokes (Anderson et al., 2009). Multiple meta-analyses and systematic reviews have confirmed this trend of decreased CVD risk with increased DF consumption, with DF coming from cereal grains having the largest impact on disease risk (Williams et al., 2020).

In addition to decreased noncommunicable disease risk, increased DF may also treat and reverse hypertension and dyslipidemia. Increased DF intake significantly decreases LDL-cholesterol values while SF specifically lowers systolic blood pressure and total cholesterol. SF has significant hypocholesterolemic effects; intakes ranging from 9g/day to 30g/day, divided into at least three servings per day, caused a weighted mean reduction of 10.6% for LDL-cholesterol values. Pectin intake, a SF, of 12g/day to 24g/day caused a 13% reduction in LDL-cholesterol values. Barley Beta-Glucan intake, a SF, was associated with an 11.1% reduction in LDL-cholesterol at just 5g/day. Although there is limited information, consumption of 5g/day of hydroxypropyl methylcellulose, a synthetic nonfermentable SF, was associated with an 8.5% decrease in LDL-cholesterol values (Anderson et al., 2009). It is important to note that these changes in LDL-cholesterol were not associated with a change in HDL-cholesterol or triglyceride concentrations. This is possibly due to SF's ability to bind to bile acids in the small intestines thereby increasing their excretion in the feces, meanwhile SF fermentation in the colon produces the SCFA propionate which may contribute to hypocholesterolemia by attenuating cholesterol synthesis (Anderson et al., 2009).

Joint Integrity and Low-Grade Inflammation

For many years now plant-based foods, particularly fruits, have been praised for their antioxidant and anti-inflammatory properties. Although it is true that fruits and vegetables are high in antioxidants and decrease inflammation, it is unclear how potent the anti-inflammatory properties of these plant-based foods are. This is due to common inflammatory foods found in western diets, foods such as refined sugars, processed foods, and fatty red meats. Due to how common the consumption of these foods is and how common low-grade inflammation and inflammatory diseases are in countries like the US, it may skew the results of studies where a diet is prescribed and inflammatory foods are reduced while also increasing anti-inflammatory foods. Regardless of this factor however, plant-based foods have been found to help treat low-grade inflammation and inflammatory diseases (Guan et al., 2021).

Plant based foods may be particularly effective in the treatment and prevention of OA and joint pain. OA is a form of arthritis caused by wear and tear in the joint leading to cartilage degradation and bone on bone contact. It can range from mild to severe and is the leading cause of disability (Dai et al., 2017). One of the more common places to develop OA is the knee. Knee OA pain and symptoms may also worsen if the individual is obese, as obesity places unnecessary load on the joint and increases total inflammation in the body (Dai et al., 2017). There are a multitude of clinical and holistic treatments including non-steroidal anti-inflammatory drugs, heat and cold therapy, and light exercise. Given the nature of OA and its vast inter-individual differences, no one treatment is perfect for everyone and often treatment plans are highly personal. However, there is one treatment and preventative measure that will work regardless of the progression of OA; especially in the instance that the individual is obese or consumes inflammatory foods regularly. This treatment is a change in diet, particularly where there is a decrease in inflammatory foods and an increase in DF rich plant-based foods. Evidence suggests that there is a significant dose-dependent inverse relationship with the consumption of TDF and OA symptoms and pain worsening. For instance, one study found that the highest quartile of TDF consumption, 26.6 g/day, had a 30% lower rate of developing knee OA and in those who had knee OA the risk of knee worsening was reduced by 19% compared to the lowest quartile who consumed 9.1g/day of DF. In the full model adjusted for diet quality, participants who consumed the highest quartile had a significant 61% lower risk for the development of knee OA compared to the lowest quartile. This study looked at two prospective US cohorts with different study designs and study populations and found that these results occurred regardless of socioeconomic status or obesity status (Dai et al., 2017).

As mentioned before, there are three primary SCFAs created by the microbiome from the fermentation and metabolization of SF. Butyrate and propionate have been identified as being capable of altering gene expression through the inhibition of histone deacetylase activity, thereby suppressing inflammatory pathways in several tissues in addition to butyrate activating anti-inflammatory cells. This anti-inflammatory mechanism produced within our colon however is often inhibited due to dysbiosis from common western diets, making it exceedingly important that TDF and SF consumption is increased in individuals who show symptoms of OA and low-grade inflammation (Koç et al., 2020).

Diabetes and Pre-Diabetes

As of 2013, approximately 382 million people worldwide suffer from diabetes and 1.5-5.1 million deaths occur annually because of diabetes. Diabetes prevalence is increasing rapidly and by 2035 the International Diabetes Federation predicts that there will be 592 million people living with diabetes (Zhao et al., 2020). Although diabetes is associated with a genetic risk such as heredity for the development of type 1 diabetes, an auto-immune condition, type 2 diabetes is largely influenced by lifestyle factors such as diet and physical activity (Zhao et al., 2020). Given that the western diet is high in refined sugar and low in DF, it can be assumed that it is also low in complex carbohydrates since these are found in whole plant foods. This directly contributes to the development of insulin resistance and insensitivity, or pre-diabetes, and eventually diabetes. Plant based foods, which are rich in naturally occurring DF, are known to reduce the risk of developing diabetes. DF is also known to improve blood glucose control in diabetics and when present in meals lowers the glycemic load of the meal helping to prevent insulin resistance. Whole grains and cereal fibers are also protective against the development of diabetes. In fact, there was a 29% reduction in the development of diabetes when individuals consumed high amounts of whole grains and cereal fibers in a 427,000 or more person cohort across eleven estimates (Anderson et al., 2009). Furthermore, the Finnish Diabetes Prevention Study found that there was 62% reduction in the progression of prediabetes to diabetes over a 4.1-year period for the highest level of TDF consumption compared to the lowest TDF consumption (Anderson et al., 2009). Increasing TDF was also found to not only aid in the control of blood glucose for people with diabetes, but also significantly reduced the use of oral medication and insulin doses (Anderson et al., 2009).

Antimicrobial Resistance

Antimicrobial resistance, or AMR, is a serious global threat to the health of humans. Evidence indicates that in 2019 there were 4.95 million deaths worldwide where AMR was an associated factor (Oliver et al., 2022). AMR is predicted to become a major cause of death worldwide by 2050. In humans, AMR is harbored within the microbiome of the colon. Microbes found within the microbiome carry genetic defenses allowing them to survive contact with antibiotics. The collection of these genetic defenses is termed the human resistome, the composition of which varies depending on lifestyle factors. For example, nonindustrialized societies with no access to modern medicine, like the Hadza people of Tanzania and ancient humans, show evidence of abundant and diverse reservoirs of bacterial antibiotic resistant genes (ARGs) within fecal metagenomes even though these populations were never exposed to modern antibiotics (Oliver et al., 2022). It appears that as microbiome diversity decreases, the presence of ARGs increases. Antibiotics are an important component of fighting disease and infection, and it appears that with the increase in abundant ARGs, there is a decrease in the effectiveness of antibiotics. Fortunately, with increased microbiome diversity there is a decrease in the prevalence of ARGs. This means that a diet high in TDF, or increasing TDF, may prevent an increase in AMR, preventing potentially harmful antibiotic resistant microorganisms from causing illness (Oliver et al., 2022).

Immune Health

Immunity may be influenced by diet, as evidenced by the consumption of inulin and other SFs enhancing immune function in humans (Anderson et al., 2009). This is most likely due to our microbiome. Within the colon there is a mucosal layer of glycoproteins responsible for protecting the body against pathogens. This mucosal layer is secreted by specialized epithelial cells called goblet cells, which use butyrate as an energy source. The mucosal layer also acts as an alternative energy source for the microorganisms found within the microbiome (Koç et al., 2020). When an individual is DF deficient, the microorganisms begin metabolizing the mucosal layer causing negative health implications to the host. Reduced TDF and SF intake causes the thinning of the mucosal layer leading to intestinal barrier dysfunction. When paired with dysbiosis, an increase in potentially pathogenic microorganisms, disease and low-grade inflammation will occur (Koç et al., 2020). To prevent this from occurring and improve immune function increased DF intake is required. This will both prevent the mucosal layer from being metabolized by the microorganisms within the microbiome and provide a steady flow of butyrate for the colonocytes responsible for producing the mucosal layer, thus improving immune function in the host (Koç et al., 2020).

Cancer Prevention

Cancer is the second leading cause of death in the US, with an estimated 1.8 million new cases and 0.6 million deaths in 2018 alone. Annual cancer rates are expected to rise to 2.3 million new cases and 1.0 million deaths by 2040. The western diet has long been associated with cancer risk due to high consumption of fatty red meat, sugar sweetened beverages, and highly processed foods with low consumption of plant-based foods. Diet associated cancer risks include oral cancer, cancer of the pharynx and larynx, colorectal cancer, uterine cancer, kidney cancer, breast cancer, pancreatic cancer, prostate cancer, thyroid cancer, gallbladder cancer, ovarian cancer, multiple myeloma, liver cancer, esophageal cancer, and gastric cancer (Anderson et al., 2009; Liu et al., 2021; Wang et al., 2021). Additionally, the 42.4% of US citizens who are obese face an increased risk of thirteen more types of cancer (Hales et al., 2020; Wang et al., 2021). Diet accounts for an estimated 80,000 new cases of cancer annually, and it is predicted that 3.04 million new cases of cancer and 1.74 million cancer associated deaths will occur for adults aged 20 and older over their lifetime (Wang et al., 2021). DF's cancer preventative attributes are well researched, current explanations include two mechanisms. Mechanism one is that DF acts as a physical barrier between carcinogenic and procarcinogenic compounds; additionally, it increases the speed of stool transit through the colon thereby decreasing the total time that carcinogenic and procarcinogenic compounds interact with the body (Anderson et al., 2009). Mechanism two is that DF provides the adequate energy and carbon the microbiome needs to produce the SCFAs propionate and butyrate. These SCFAs can alter gene expression by inhibiting histone deacetylase thereby suppressing tumor growth in many tissues in addition to the previously mentioned suppression of inflammatory pathways. Butyrate also has anti-cancer properties as well as the previously mentioned anti-inflammatory properties (Koç et al., 2020).

Whole grains and cereal fiber continue to provide protective benefits, especially in cancer prevention. Current evidence suggests a dose-dependent relationship between cancer prevention and whole grain/cereal fiber consumption. For every 10g/day increased consumption of cereal/grain fiber there was an associated 9% reduction in the risk of developing colorectal cancer. This relationship appears linear with no clear upper limit where cancer risk reduction decreases from 9% (Oh et al., 2019). Furthermore, there was an associated 22% reduction in liver cancer risk with the highest whole grain intake compared to the lowest whole grain intake and a 31% reduction in liver cancer risk with the highest TDF, after multivariable adjustment (Liu et al., 2021).

Obesity Prevention and Treatment

Obesity is one of the many epidemics the US faces. Obesity itself is a disease characterized by an excess presence of body fat, typically diagnosed using a BMI chart; although currently the use of BMI may be controversial to use when diagnosing an individual and is best used for large populations. Obesity impacts many aspects of life and is multifactorial, making it incredibly difficult to treat. Treatments range from exercise and diet all the way to major surgeries. Diet changes are considered the best prevention for the development of obesity and will typically be the most accessible treatment for obesity. Although a total diet change is recommended, evidence suggests that when TDF is increased regardless of energy intake weight loss occurs. This weight loss appears to be dose-dependent and increases with greater DF consumption. In one study, a high fiber diet of 48g/day saw an 8% decrease in energy absorption compared to the low fiber diet of 20g/day (Howarth et al., 2001). This translates to a 160-calorie difference per day if the energy intake is 2,000 calories per day. Additionally, when energy intake was ad libitum an additional 14g/day of DF was associated with a 10% decrease in energy intake and a 1.9kg loss of body weight over 3.8 months (Howarth et al., 2001). Energy intake suppression appears to be particularly potent for overweight/obese individuals compared to lean individuals. When TDF was increased, mean energy intake decreased to 82% for the overweight/obese participants whereas mean energy intake was decreased to 94% in lean participants; this translated to a 2.4kg decrease in body weight compared to 0.8kg decrease respectively (Howarth et al., 2001). These changes occurred with DF coming from whole foods as well as supplements (Howarth et al., 2001).

TDF elicits weight loss by increasing fecal energy loss, increasing satiety, and increasing the production of butyrate, a SCFA, which has anti-obesogenic effects (Koç et al., 2020). Fecal energy loss occurs due to the net-zero energy availability of DF (Howarth et al., 2001). Although we absorb the SCFAs produced in the colon by the microbiome, DF also restricts the absorption of fat and protein by preventing physical contact with the villi of the gastrointestinal tract as well as decreasing the total time available for macronutrient absorption; thus, DF is 0 calories (Anderson et al., 2009; Howarth et al., 2001). Furthermore, SF delays gastric emptying and enhances satiety post-meal. This enhanced satiety most likely accounts for the 18% reduction in mean energy intake with ad libitum diets previously mentioned (Anderson et al., 2009; Howarth et al., 2001).

Health Behavior and Awareness

According to current health behavior and consumer survey evidence, nutritionally redefining DF as an independent macronutrient rather than a subset of carbohydrate may yield greater intakes of DF. Although the general population reports that they understand the immediate benefits of DF and believe that they adequately consume DF; only 5% of all people in the US adequately consume DF in a day (Quagliani & Felt-Gunderson, 2015). DF has been identified since 2005 as a nutrient of concern and change is required to increase nationwide intake (Quagliani & Felt-Gunderson, 2015). The reasons for such widespread DF deficiency, compared to other macronutrients, are multifactorial. One contributing factor may be due to the lack of comprehensive science-based nutrition education in public schools, leading to confusion on what foods are good sources of DF, how much DF to consume, and how to accurately track it. Additionally, popular food trends and fad diets such as gluten free and keto may contribute to lower DF intake as these diets limit the amount of plant-based foods consumed, particularly whole grains. According to the International Food Information Council, 68% of survey takers identified DF as a food component that influenced their decision of what foods to buy, 62% said they are trying to eat more fiber; with 88% increasing their fruits and vegetables intake and 78% increasing their whole grain intake to increase their DF (Quagliani & Felt-Gunderson, 2015). However, only 25% of survey takers reported examining the nutrition facts label every time they purchased a whole grain product. Furthermore, objective observational research in the grocery aisle indicates that less than 15% of consumers look anywhere other than the front panel of packaged foods (Quagliani & Felt-Gunderson, 2015). These surveys indicate that the gap between recommendation and consumption may be caused not by nutrition illiteracy, but by consumer products not providing an easy way for purchasers to distinguish the nutritional content of products.

A brief observation of any grocery aisle will illustrate why DF intake is so low. Apart from "healthful" products from brands such as Fiber One, Dave's Killer Bread, and Quaker Oats; TDF per serving is not listed on the front-of-pack nutrition label, or FoPL. What is listed however are ingredients you should ordinarily avoid, such as a high sodium content or sugar content. Should DF be redefined as a macronutrient, efforts to update nutrition label requirements to include a FoPL with all four macronutrients may be streamlined and encourage a new wave of research identifying the effectiveness of the proposed definitions. A FoPL that includes TDF per serving may increase the number of products purchased that have higher DF per serving than products with similar price and palatability. The rational for changes in purchased products is supported by the survey takers who report understanding the health benefits that DF provides and strive to increase their intake while also rarely looking at the nutrition facts label on the back of the package (Egnell et al., 2021; Quagliani & Felt-Gunderson, 2015).

Conclusion

TDF intake is chronically low in the US and only 5% of the population consumes adequate TDF (Quagliani & Felt-Gunderson, 2015). Adequate DF is associated with a significantly decreased risk of the following health concerns; obesity, cancer, diabetes and prediabetes, OA, low-grade inflammation, AMR, CHD, hypertension, dyslipidemia, constipation, and dysbiosis (Anderson et al., 2009; Dai et al., 2017; Guan et al., 2021; Koç et al., 2020; Liu et al., 2021; Oliver et al., 2022; Stewart & Schroeder, 2013; Wang et al., 2021). Adequate DF is also associated with weight loss and weight maintenance, blood glucose regulation in diabetics, decreased pain associated with OA, decreased inflammation, decreased concentration of ARGs, decreased blood pressure, improved serum lipid concentrations, regularity, and increased microbiome diversity (Anderson et al., 2009; Dai et al., 2017; Guan et al., 2021; Koç et al., 2020; Liu et al., 2021; Oliver et al., 2022; Stewart & Schroeder, 2013; Wang et al., 2021). Nutritionally redefining DF as the fourth macronutrient and including it on FoPLs may lead to increased consumption of TDF thereby lowering the risks of and treating the illnesses and diseases listed above (Egnell et al., 2021; Quagliani & Felt-Gunderson, 2015).

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