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DIETARY FIBER: How Did We Get Where We Are?

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■ **Abstract** Dietary fiber has been a topic of considerable interest among nutritionists and clinicians for the past 50 years. Many studies on fiber have concentrated on fiber isolates, resulting in findings that have ignored fiber as a component of fruits, vegetables, nuts, cereals, and legumes in the general diet. The principle actions of fiber are to alter the nature of the contents of the gastrointestinal tract and to modify the absorption of other nutrients and chemicals. Fiber is but one component of plant food, and to neglect the other components—be they proteins, lipids, vitamins, minerals, antioxidants, or the secondary metabolites—is to seriously limit our understanding. Much of the effort expended in defining fiber and studying the fiber isolate would have been better focused using this whole-plant-food approach. Greater progress in our understanding of the relevance of fiber in the etiology of disease would have been achieved if a more holistic approach had been followed.

CONTENTS

EVOLUTION IN THE UNDERSTANDING OF DIETARY FIBER

Nutritionists and the public have not been consistent in their regard of fiber in the diet. Some have considered fiber as an integral part of the diet. For others, refinement of food, cereals in particular (especially in bread), and extraction of fruit juices, which are then fermented and even distilled to form alcoholic drinks, implies sophistication.

Throughout recorded history, the merit of whole foods has been emphasized by various writers beginning with Hippocrates, then Stubs and Tyron in the sixteenth century, and onto the nineteenth century with Graham (24) in the United States and Allinson (5) and Hurst (27) in Great Britain. In the United States, Kellogg (28) taught that whole cereal foods were important for health, whereas Alvarez (3) viewed humans as carnivores and condemned the use of extra roughage. Few of these strongly held opinions were supported by experimentation; exceptions include McCarrison (34), who served in the Indian Medical Service.

During the nineteenth and early twentieth century, advances were made in the analytical methodology of food components, including water, nitrogenous materials, and lipids, which leave a carbohydrate residue. Nutritionists required a more precise breakdown, and a crude fiber analysis, using acid and alkaline digestion-simulating events in the upper gastrointestinal tract, was developed by the Weende Experimental Station in Germany. This method was subsequently refined by Rubner and his colleagues (39). Atwater (8), at the turn of the twentieth century, showed that foods containing crude fiber increased fecal energy losses but crude fiber itself did not contribute to the metabolizable energy of the body. In their treatise, "The Chemical Composition of Foods," McCance & Widdowson (33) tackled the problem of analyzing food composition. They considered dietary carbohydrates as either available or unavailable. Available carbohydrates were absorbed in the foregut and were glucogenic. Unavailable carbohydrates (or roughage) were the indigestible structural carbohydrates (nonstarch polysaccharides and lignin) from the plant cell wall. Animal metabolic studies had shown that this unavailable carbohydrate was fermented in the colon, yielding short-chain fatty acids. Williams & Olmsted (47) also developed methods for analyzing available carbohydrates and the indigestible polysaccharides, hemicelluloses, cellulose, and lignin. Hellendoorn (26) emphasized the importance in colonic physiology of short-chain fatty acids released by fermentation in the colon.

Subsequent research on fiber has followed two paths, one physiological, the other committed to etiology and epidemiology. An early experiment was to measure the distribution of bile acids along the small intestine of the rat; contrary to expectations, the greatest amount was found in the ileum, where bile acids are absorbed (20). Increasing the fiber content of the diet of rats increased the pool of bile acids and the amount of these acids in the ileum. Subsequently, fiber—particularly lignin—was shown to adsorb bile acids (21). This led to two experiments in human male subjects, one conducted in a Trappist Cistercian monastery, and the other with volunteers. Each failed to show any hypocholesterolemic influence of increased dietary fiber or wheat bran (17, 22). The latter experiment was of additional interest: The length of each trial period was three weeks, which was the time available between a medical faculty ball and Christmas. This period has since been used in a number of experiments.

In separate studies, Kritchevsky & Tepper (31) showed that the protective effect of a commercial chow diet against the development of atheroma was not due to the small amount of unsaturated fat present but rather to the presence of fiber in the chow. Subsequent experiments with other polysaccharides (29) showed a consistent influence of fiber on lipid metabolism in animals. This finding led to experiments that showed fiber's ability to adsorb bile acids (30).

Cleave (16) argued lucidly that many of the diseases that are a product of civilization were secondary to those resulting from the consumption of refined or fiber-depleted carbohydrate foods, including sugar as well as white flour. Independently, Burkitt (13), Painter (36), Trowell (43), and Walker (45) convinced nutritionists and the public that fiber deficiency was a real problem.

While investigating his eponymous tumor, Burkitt had traveled widely in Africa to establish the peculiar geographical distribution of this cancer. He became puzzled by the apparent rarity of many surgical and medical diseases in black Africans, disorders that were common in Europe and in white Africans (13). Soon Burkitt started to diverge from the major point of Cleave's hypothesis by relating appendicitis, colorectal cancer, hemorrhoids, and varicose veins to low fiber intakes rather than to high sugar consumption. In the 1970s, Burkitt was joined by Trowell (43), Painter (36), and Walker (45) in declaiming that the low prevalence in developing countries of diabetes, gall stones, ischemic vascular disease, obesity and diverticular disorder, large bowel cancer, appendicitis, hiatal hernia, varicose veins, and hemorrhoids—all of which are commonly seen in Western countries—was due to diet, particularly to the greater amount of fiber consumed. Painter et al. (37) made the important observation that increased dietary fiber, particularly wheat bran, alleviated the symptoms of patients with diverticulosis, a condition that had long been treated with low-residue diets. This observation did much to stimulate the present intensive study of dietary fiber because it was based on objective evidence rather than extrapolations from observations and epidemiological evidence. Interest in fiber burgeoned, and fiber became important as a nutritional debating point and as a topic for research.

To study dietary fiber, two requirements had to be met. First, the definition of fiber had to be agreed upon. The debate over the definition of dietary fiber began before the publication of Trowell's paper in 1972 (43). His definition was viewed by some as too imprecise to be used to develop the quantitative studies that were essential for testing the epidemiological elements of the hypothesis (41, 42). Trowell's various definitions always contained three criteria for dietary fiber: a physiological, a botanical, and a chemical. Of these, only the first criterion, i.e., the resistance of dietary fiber against human digestive enzymes, has remained unchanged throughout the years. The botanical description changed from "skeletal remains of plant cells," to "remnants of plant cells," to "remnants of the plant cell wall," to "structural polymers of the plant cell wall." Trowell's chemical descriptions of dietary fiber were not precise and changed repeatedly. The American Association of Cereal Chemists' Fiber Definition Committee presented its definition of dietary fiber under the title "All Dietary Fiber is Fundamentally Functional." The committee defined dietary fiber as "functional, and if a fiber exhibits the requisite functionality(ies), it is dietary fiber, no matter what its source or history" (4).

The debate over developing a comprehensive definition for fiber continues today, and no single analytical strategy is fully able to incorporate all requirements. This is because both fiber and starch are omnipresent together in plant foods, and the physiological status of both dietary fiber and starch, e.g., resistant starch, is variable (23a, 40). Englyst & Cummings (23) proposed replacing the term "dietary fiber" with "non-starch polysaccharides." Heaton and colleagues (25) stressed the importance of the physical state of fiber, which is not usually emphasized in fiber definitions.

Second, methods of analysis had to be determined to study fiber. These methods of analysis have developed along two principle and different pathways (23, 35, 38, 42, 44): (*a*) gravimetric methods, in which the fiber is isolated and weighed, and (*b*) component analysis methods, in which dietary fiber constituents are determined more or less specifically.

Burkitt, Trowell, Painter, and Walker enthusiastically promoted the virtues of increasing the fiber content of the diet, and based their recommendations on what they perceived to be a self-evident fact, not a hypothesis (14, 36, 45). Although appealing to many, their lectures were not well received by all. They were clinicians, not nutritionists and, as most professionals with a medical clinical training, did not welcome polypharmacy. They preferred to focus on a single entity in the diet. They developed a reductionist approach, in contrast to the nutritionist's view of a rounded, complete diet in which all components are adequately represented. Perhaps Cleave's hypothesis (16) was closer to the view with which nutritionists currently would feel most comfortable.

Thirty-two years have passed since the British Nutrition Society hosted the first conference on dietary fiber in Edinburgh. Approximately 10,000 papers have been published since the 1950s on the topic of dietary fiber. Once attributed to a low-fiber diet, duodenal ulceration has been shown to be caused by *helicobacter pylorus*, and researchers have found other etiologies for hypertension, hiatus hernia, deep vein thrombosis, and diabetes.

What would have happened if Burkitt and Trowell had emphasized the value of plant foods? The epidemiology of the value of fruits, vegetables, and cereal grains (6), as opposed to only fiber, has proved to be much more consistent. The value of eating plant food, which incorporates dietary fiber and plant metabolites, might have been the focus of attention rather than fiber as one specific isolate (16, 18, 19).

Dietary fiber has never been formally accepted or proposed as an essential component of the diet. However, a diet containing little fiber has been blamed for many of the chronic diseases of modern society. The assumed importance of dietary fiber has been in its putative role in preventing a number of chronic and sometimes mortal conditions. This assumption led to discoveries relating to dietary fiber being accorded comparable significance to those of the discovery of vitamins, essential amino acids, and fatty acids. The influences of dietary fiber on a number of diseases (including heart disease, colonic diverticulosis, and cancer) are discussed at length in chapters in a recent compendium on fiber (15). It is evident that few indisputable effects of fiber alone have been identified. It is possible that the only condition with a clear etiological association with a low fiber-containing diet is the development of colonic diverticulosis (46).

THE METABOLIC FATE OF FERMENTABLE FIBERS: NEW DIRECTIONS

Dietary fiber has been described as a substance impervious to degradation by our endogenous enzymes. Fermentable fibers are degraded by the intestinal flora to yield short-chain fatty acids. However, when ^{14}C-labeled fiber is fed to rats, ^{14}C is incorporated into tissues in several forms. How these products affect overall metabolism remains to be elucidated. Uniformly labeled primary cells walls (^{14}C-PCW) were obtained by growing spinach cultures in a medium containing D-[U^{14}C-glucose]. The preparation yielded ^{14}C-homogalacturonan (30% of recovered ^{14}C), ^{14}C-rhamnogalacturonan (23% of recovered ^{14}C), other hemicelluloses (3% of recovered ^{14}C), and cellulose (21% of recovered ^{14}C). There were small amounts (<3%) of ^{14}C-protein and ^{14}C-starch. Recovered lignan was unlabeled. The pectic fraction of the plant cell walls was preferentially degraded completely in the gastrointestinal tract. Of the total ^{14}C dose, 22% was recovered in the host liver, adipose tissue, and skin; 26% was excreted as $^{14}CO_2$; and 18% appeared in the feces. ^{14}C was found in all tissues of the body, but it was particularly concentrated in the adrenal glands, colon, and cecum. ^{14}C was also recovered from the liver, where it was present predominantly in phospholipid, and in the skin, where it was present in protein and in fatty acids esterified into cholesterol.

When spinach cultures were incubated with D-[6-^{14}C] glucuronic acid, more than 85% of the label appeared at the C6 position of pectic galaturonic residues. A second preparation contained ^{14}C in the pectic methyl ester group. Rats fed uronate-labeled pectin excreted 37% of the label as $^{14}CO_2$, and those fed methyl-labeled pectin excreted 18%. In both studies, ^{14}C was recovered from the liver, mainly as protein (principally alanine), and in fatty acids esterified to cholesterol. In rats fed ^{14}C-labeled gelatinized starch, 25% of the ^{14}C was expressed as $^{14}CO_2$. When rats were fed resistant starch, ^{14}C was accumulated in muscle, skin, liver, and intestinal tissues.

These studies demonstrate both bacterial fermentation and host metabolism of the fermentation products. The study of pectin and starch metabolism under any number of physiological circumstances is now possible (1, 2, 9–12).

CONCLUSIONS

Dietary fiber has been and continues to be an exciting topic to explore. In retrospect, it was a mistake—possibly a necessary mistake—to isolate fiber from the overall field of plant food nutrition. One possible explanation for this is that clinicians

TABLE 1 Specific anticarcinogenic phytochemicals

Allium components	Isothiocyanates
Carotenoids	Limonene
Coumarins	Phenols
Flavonoids	Plant sterols
Folic acid	Saponins
Glucosinolates	Selenium
Indoles	Thiocyanates
Inositol hexaphosphate	Vitamin C
Isoflavones	Vitamin E

who were active in this field had medical training that emphasizes single-treatment regimes. As a result, research was focused on a single item. One bullet is enough, and more confuses.

The principle actions of fiber are to alter the nature of the contents of the gastrointestinal tract and to modify the absorption of other nutrients and chemicals. Plant whole foods are of fundamental importance in our diet. Although fiber is found in fruits, vegetables, nuts, cereals, and legumes, it is but one component of that plant food. Neglecting the other components, whether they be proteins, lipids, vitamins, minerals, antioxidants, or secondary metabolites, limits our understanding. Much of the effort on defining fiber and studying the fiber isolate would have been better applied to a whole-plant-food approach (see Table 1).

The mantra of five fruits and vegetables a day is an attempt to be holistic in approach. However, the value of this recommendation is blunted by not specifying which five, and whether they should be roots, stalks, red, green, or yellow. What components of these fruits, vegetables, nuts, and legumes are important? Our belief is that the list of important components of plant foods is only just beginning to be made, and in the future, secondary metabolites will be recognized as important. When they are identified, they should be fitted into this holistic nutritional approach rather than heralded, as with fiber, as an isolate that does everything. To complicate things further is the finding that, coincidental with intensive farming, the nutrient content of plants may vary (32). Another unexplored element is the possibility that individual needs may vary depending on the genetic makeup of the individual.

Nutrition is about food. Interest in a single component may further our understanding of the whole, but should not suggest supremacy of any one item. An analogy is the orchestra: It is important to discuss and understand each instrument, yet we must also recognize how the instruments interrelate. In the study of food, the nutritionist is the conductor, not the composer.

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