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Dietary fiber and metabolic syndrome: A complex relationship

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Abstract
Metabolic Syndrome (MetS) is a complex web of metabolic risk factors that are linked with a 2-fold risk of CVD and a 5-fold risk of diabetes. Individuals with MS have a 30%-40% likelihood of developing CVD within 20 years; depending on the number of components they have. The main features of MetS include abdominal obesity, high blood pressure, hyperglycemia/insulin resistance, and dyslipidemia. The most commonly used criteria for diagnosis of MetS are the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP-III) and the International Diabetes Federation (IDF), both of which include fasting plasma glucose, blood pressure, triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), and body fat (waist circumference). MetS has become a global public health issue. Its prevalence has been estimated to vary between 20-27% in adults from developing countries, and even higher in developed nations. Approximately 20-25% of the world adult population suffers from MS disorders and in India, the prevalence of MS is increasing exponentially as determined by 33.5% overall, 24.9% in males and 42.3% in female on the basis of The National Cholesterol Education Program's Adult Treatment Panel III (ATP III) diagnostic criteria. Preventing and treating this syndrome is an area of public health urgency from the perspective of improving the morbidity and mortality statistics as well as in reducing its economic burden.
Recent evidences suggest that increasing the fiber intake through dietary intervention is a safe and practical approach to improving the burden of this syndrome. Within recent years, the US (FDA), (2001) has endorsed the relation between an increase in soluble fiber and a decrease in serum total cholesterol by ratifying health claims for oats and for psyllium fiber. The active component in oats has been identified as the linear mixed-link (1→3) (1→4) β-D-glucan (β-glucan), which reduces serum total cholesterol by 5-10% and which in oats is present at close to 4% (by wt).
Recent evidences suggest that dietary fiber that is rich in whole and unrefined grains is protective and plays an important role in preventing or delaying the onset of these lifestyle diseases such as coronary heart disease, diabetes mellitus, cancer, and colon dysfunction.

Keywords: Whole grains, metabolic syndrome, dietary fiber, CVD, etc.

Introduction

Mechanisms Involved in Dietary Fiber Consumption and MetS

The exact mechanisms of the complex pathways of metabolic syndrome are not clear yet, but it is known to be a complex interaction between genetic, metabolic and environmental factors. Interest has increased in the use of diet and lifestyle rather than drugs for the prevention and management of hypertension and cardiovascular disease. Now a day's reducing the incidence of CVD through dietary intervention is a major focus of health organizations worldwide as the Dietary habits are highly modifiable and can be a potent risk factor for the development of CHD. According to the American Association of Cereal Chemists, dietary fiber consists of edible parts of plants that resist digestion and absorption in the small intestine, with complete or partial fermentation in the large intestine. Dietary fiber is considered to be a useful functional food, i.e., a food with health benefits, in many situations: its benefits for health maintenance and disease prevention. An adequate diet rich in fiber also contains minerals, vitamins, phenols, phytoestrogens and unsaturated fatty acids, which also contribute to the properties of healthy diet. Although dietary fiber can be provided in the diet by natural sources such as cereals, fruits, vegetables or legumes or by supplement [10]. Cereals are mainly considered a good source of insoluble fiber, as majority of grains, including wheat, rice or rye contain a large amount of this type of dietary fiber. Cereals usually contain relatively low quantity (About 25%) of soluble fiber.

Legumes constitute important sources of both types of fiber. The fiber content of fruits and vegetables is generally lower than that of cereals and legumes and consists mainly of the soluble type [11]. On the basis of water solubility, dietary fiber can be divided into insoluble and soluble fiber.

Insoluble dietary fiber

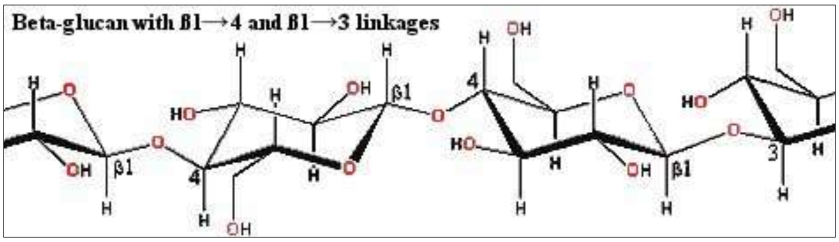
Cellulose, lignin, some pectins, and some hemicelluloses are insoluble fibers. Vegetables and cereal grains are especially rich in insoluble fiber, with the highest amounts in wheat and corn. Insoluble fiber is responsible for increased stool bulk and helps to regulate bowel movements.

Soluble dietary fiber

The natural gel-forming fibers, such as β- glucans, gums, mucilages (e.g. psyllium), pectins, and some hemicelluloses are soluble. Foods rich in soluble fiber are dried beans, oats, barley, and some fruits and vegetables. The mean total daily fiber intake amongst adults in most industrialized countries is well below 25 g, the minimal amount recommended by various health organizations. Of total dietary fiber intake, approximately 20% should be soluble and 80% should be insoluble.

What is Soluble Fiber (β-glucans)?

β-Glucan is a viscous soluble fiber found in cereals, in particular oats and barley, as well as in yeast, bacteria, algae, and mushrooms. β-glucans are non-starch polysaccharides composed of glucose molecules in long linear glucose polymers with mixed β-(1→4) and β-(1→3) links with an approximate distribution of 70% to 30%.



This specific chemical structure is responsible for physical properties, such as viscosity and solubility, as well as the potential to influence cholesterol metabolism. Numerous studies demonstrated that diets high in soluble fiber grains (Oats, barley) lower blood cholesterol more than diets high in more insoluble grains (Wheat, rice) (Behall *et al*. 1997, Leinonen *et al*. 2000, Bruce B *et al*. 2000, Bridges SR 1992) [22-25]. A meta-analysis by Brown *et al*. (1999) [26] showed that daily intake of 2-10 grams of soluble fiber significantly lowered serum total cholesterol and LDL-cholesterol concentrations.

How Beta-Glucans Work? Several of the principal benefits of soluble fiber in metabolic syndrome patients are indisputably due to its effect on carbohydrate absorption. Viscous fibers such as psyllium, β-glucans, and pectin may form a gel in the small intestine, which acts to delay nutrient absorption, slowing the delivery of glucose into the bloodstream and reducing the need for insulin. These fibers' ability to lower postprandial glycemia and insulinemia, as well as cholesterol, has been established in numerous studies, but long-term effects are less well known. Bacteria ferment β-glucans in the intestinal tract, producing short-chain fatty acids. These may stimulate insulin release from the pancreas and alter glycogen breakdown by the liver and therefore play a role in glucose metabolism and protect against insulin resistance.

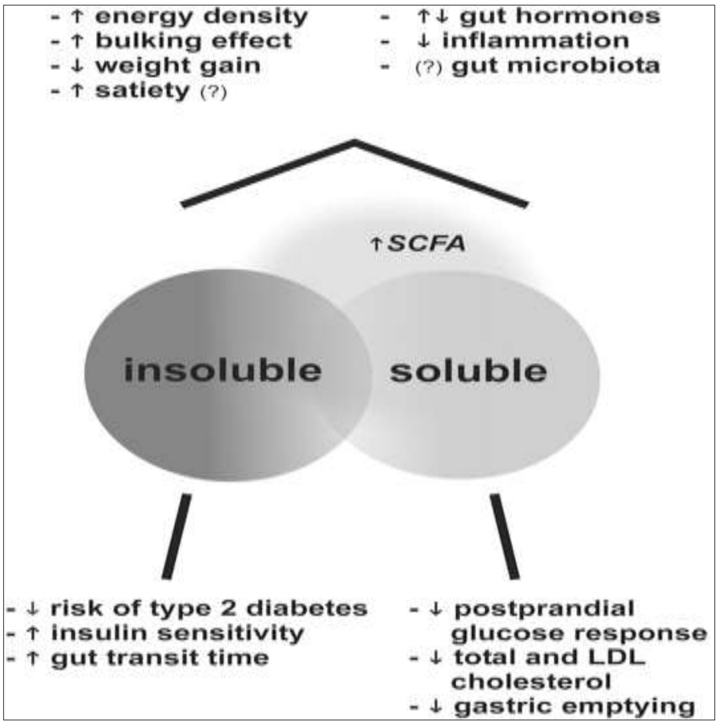


Fig 1: Potential effects of Dietary Fiber (DF) consumption

The association between dietary fiber intake and individual components of MetS has been extensively investigated and supported in both observation and intervention studies. Potential mechanisms for health benefits of dietary fiber on MetS are summarized below.

Dietary Fiber and Obesity

Observation studies have constantly highlighted the inverse association between dietary fiber consumption and increase in body weight, BMI or waist circumference. Dietary fiber was also suggested to promote weight loss in obese or overweight individuals and prevent their weight regain. Epidemiological evidence of dietary fiber consumption and obesity or weight regulation has been well reviewed [12]. The mechanisms of dietary fiber on obesity are suggested to be related to energy dilution, reduction in nutrients absorption rate, appetite suppression, regulation of energy homeostasis, and alternation of gut microbial. Dietary fiber consumption level, physicochemical properties (e.g., solubility and viscosity), ferment ability and molecular structure may result in difference in weight regulation.

Dietary Fiber and Insulin Resistance/ Hyperglycemia

Dietary fiber is associated with a reduced risk of diabetes and cardiovascular disease, and high intake of dietary fiber is associated with enhanced insulin sensitivity [13]. Soluble dietary fiber has been reported to reduce postprandial glucose levels and to improve insulin sensitivity in both diabetic and non-diabetic persons. It also favours increased glucose uptake into skeletal muscle and improves insulin sensitivity by increasing the viscosity of the stomach contents and impeding digestion of carbohydrate and absorption of macronutrients. A study in hypertensive rats suggests that psyllium supplementation effectively prevents insulin resistance by increasing skeletal muscle plasma membrane content of the insulin- responsive glucose transporter Type 4 (GLUT-4). A hypothesis highlighting that a series of fatty acids stimulate peroxisome proliferator activated receptor (PPAR) o&, whose activation has been reported to increase GLUT-4 content in adipocytes. Therefore short chain fatty acids (SCFAs), such as propionic and butyric acids, which result from anaerobic bacterial fermentation of soluble fermentable dietary fiber in the colon, increase muscle GLUT-4 via PPARo [14].

Table 1: Effect of fiber intake on hyperglycemia and insulin resistance

Author	Study design	Major findings
Anderson *et al.* [15]	After a 2-week dietary Randomized, double-blind, placebo-controlled parallel study in 34 men, aged 30-70 years, with Type 2 diabetes and mild to moderate hypercholesterolemia. Stabilization phase consuming a diet for diabetes, subjects followed an 8-week treatment phase consuming the diet and receiving either 5.1 g psyllium or cellulose placebo twice daily.	All-day and post lunch postprandial glucose concentrations were 11.0% ($p<0.05$) and 19.2% ($p<0.01$) lower in the psyllium than in the cellulose placebo group.
Sierra *et al.* [16]	Clinical study in three phases among 20 Type 2 diabetic patients. Phase 1 (1 week), Phase 2 (treatment, 14 g of psyllium/day, 6 weeks) and Phase 3 (4 weeks). Phases 1 and 3: diet for diabetes plus sulfonylurea treatment.	The glucose AUC in the presence of fiber (Phase 2) was significantly lower (12.2% and 11.9%, respectively) than those obtained at the end of Phases1 and 3. Insulin AUC decreased by 5% in Phase 2 compared with the value in Phase 1 and was 15% lower than in Phase 3, although no significant differences were observed.
Weickert *et al.* [17]	Randomized, controlled, single-blind, crossover study among 17 overweight or obese subjects with normal glucose metabolism. Diet: three macronutrient-matched portions of fiber-enriched oat bread or control (white bread) over 72 h.	Intake of fiber-enriched bread significantly improved whole-body glucose disposal, equivalent to an 8% improvement of insulin sensitivity. Mean insulin concentrations were not significantly changed after fiber intake compared with control. Accordingly, mean insulin action was significantly enhanced by 12% after fiber intake.

Dietary Fiber and Type 2 Diabetes Mellitus

Consumption of dietary fiber is shown to lower the risk of T2DM in observation studies and meta-analyses. Improved insulin resistance and glucose tolerance in T2DM patients or impaired glucose tolerance subjects was also observed in intervention studies [18]. The beneficial effects of dietary fiber on insulin resistance attributes to increasing food glycemic index, reducing the risk of obesity, improving subjects' glucose homeostasis, regulating hormonal responses, modulating inflammatory cytokines, and altering gut microbiota [19]. The effect of dietary fiber on GI is related to its physicochemical properties including particle size, amount and type of fiber, viscosity, amylose and amylopectin content, delaying gastric emptying time, and reducing glucose absorption.

Dietary Fiber and Dyslipidemia

Hypocholesterolemic property of soluble fiber is consistently observed in observation studies and meta-analyses of randomized controlled trials. Viscosity of fiber plays a major role in the cholesterol lowering effect. Soluble fiber of high viscosity reduces plasma cholesterol to a greater extent than insoluble fiber or very low viscosity fiber. The cholesterol lowering effect of soluble dietary fiber may attribute to increased fecal bile salts excretion, reduced glycemic response of food, and fermentation products of soluble dietary fiber [20]. Cholesterol lowering effect of insoluble fiber is observed in some studies and the mechanism is attributed to promotion of satiation and satiety. Dietary fiber's hypotriglyceridemic effects is postulated due to the delayed and reduced absorption of TG and sugars from the small intestine, modulation of fatty acid synthase activity, decreasing the GI and its impact on homeostasis and insulin secretion.

Dietary Fiber and Hypertension

An inverse relationship between dietary fiber intake and blood pressure has been observed in several population studies [21]. Meta-analyses of randomized controlled trials demonstrated that dietary fiber supplementation or intervention of high-fiber diet may result in statistically significant decrease in diastolic blood pressure. Mechanisms behind the effects of dietary fiber on blood pressure reduction are still unclear. Increasing dietary fiber may lower the risk of hypertension by controlling the risk factors, such as improving insulin resistance and reducing LDL-C. High intake of fiber could also modify gut microbiota populations and increase the abundance of acetate-producing bacteria.

Conclusion

Dietary fiber exerts clinical benefits on all the abnormalities clustered in the metabolic syndrome, since it has been shown to reduce body weight gain, dyslipidemia and hypertension and to improve insulin sensitivity in altered inflammatory markers associated with metabolic syndrome both in human studies and in experimental models. As some inherent limitations in the original studies were observed, it is recommended that important potential confounding factors, such as physical activity, should be taken into account (e.g., by statistical adjustment) in further studies. The effect of fiber types on the risk of MetS is also an interesting subject for further investigation. Soluble gel-forming fibers regulate most of the metabolic disturbances clustered in this syndrome by different mechanisms linked to their gel-forming capability and their fermentability in the colon. Non-viscous insoluble fibers contribute to ameliorate some of the same abnormalities. Both types of fibers are beneficial and probably complementary to reduce risk of cardiovascular disease and Type 2 diabetes. In conclusion, this dietary strategy holds great control and appears to be beneficial in human health.

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