A High-Carbohydrate, High-Fiber Meal Improves Endothelial Function in Adults With the Metabolic Syndrome

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Brachial artery flow-mediated dilation (FMD) using high-resolution ultrasound is a well-accepted, noninvasive bioassay for in vivo endothelium-generated nitric oxide (NO) in humans (1). Impaired NO generation characterizes the endothelial phenotype prone to the development of atherosclerosis and is linked to acute cardiovascular events. In several studies (2,3), endothelial dysfunction is an independent predictor of future cardiovascular morbidity and mortality. The postprandial state may be critical in the development of atherosclerosis (4). A single high-fat meal can induce endothelial dysfunction, whereas low-fat meals generally neither improve nor worsen FMD (5–8). The lack of a reported effect of low-fat meals on FMD may be attributable in part to insufficient dietary fiber in the meal. In particular, increased cereal fiber consumption is associated with reduced cardiovascular disease incidence and mortality (9–11) and lower prevalence of the metabolic syndrome (12) and may reduce systemic inflammation (13). We examined whether a high-carbohydrate meal, rich in cereal fiber, would improve brachial artery FMD in adults with the metabolic syndrome. For comparison, we also examined the impact of a low-carbohydrate, low-fiber meal.

RESEARCH DESIGN AND METHODS — Twelve (9 women and 3 men: 44.7 ± 7.9 years of age, 98.9 ± 16.6 kg, 1.70 ± 0.07 m) nonsmoking, nondiabetic adults who met the International Diabetes Federation criteria for the metabolic syndrome participated in the study (14). Subjects were not taking medications to control blood lipids, blood pressure, or blood glucose.

Brachial artery FMD was used to examine endothelial-dependent function, and a 400-μg sublingual dose of nitroglycerin was used to examine endothelial-independent vasodilation. The same blinded sonographer was used for all imaging studies, and brachial artery measurements were obtained using two-dimensional and Doppler ultrasound measurements (HDI 5000, ATL; Philips Ultrasound, Andover, MA) with a linear array transducer at a transmit frequency of 12 MHz. All digital images were acquired in accordance with the guidelines of the International Brachial Artery Reactivity Task Force (15) and analyzed with custom-designed edge-detection and wall-tracking software (Brachial Analyzer; Medical Imaging Applications, Iowa City, IA). The same image reader was used for all analysis, and the lumen-intima interface was used to determine vessel diameter.

Images were obtained on each subject's extended nondominant arm, which was immobilized by supports. Heart rate triggers were applied to capture digital still images at the onset of the Q wave. Three baseline images were captured after identification of a segment with a clear anterior and posterior intimal interface between the lumen and vessel wall. A pressure cuff placed 2 cm distal of the antecubital fold was inflated to 50 mmHg above systolic blood pressure for 5 min. After rapid deflation of the cuff, digital still images were captured every 5 s from 30 to 120 s to determine peak dilation. Fifteen minutes later, the procedure was repeated with nitroglycerin administration.

Following an overnight fast, subjects were imaged at baseline and 4 h postprandially. The order of the meals was randomized, and each subject received both meals. All meals were prepared and consumed at the general clinical research center's metabolic kitchen and contained between 535 and 900 kcal, depending on age, sex, weight, and height (16).

The high-carbohydrate, high-fiber meal contained 50 g All-Bran cereal (Kellogg), 70 g whole-wheat bread, 218 ml nonfat milk, 107–214 ml cranberry juice, 19 g assorted jellies, and 4.3–8.6 g margarine, with a macronutrient composition of 69–76% carbohydrate (19 g cereal fiber), 12–18% fat (1.9–6.4 g saturated, 3.6–4.0 g monounsaturated, and 1.9–2.5 g polyunsaturated), and 13–15% protein. The low-carbohydrate meal contained two to three eggs, 28.4–56.8 g cheddar cheese, two to three turkey sausage patties, 220 ml whole milk, 108 ml orange juice, 23 g mushrooms, and 8.6 g margarine, with a macronutrient composition of 12–16% carbohydrate (0.5 g fiber), 58–61% fat (16.5–25.2 g saturated, 14.5–20.3 g monounsaturated, and 5.4–7.1 g polyunsaturated), and 26–28% protein. A 2 × 2 ANOVA with repeated measures was used to assess differences in FMD between diets.

RESULTS — Resting brachial artery diameter (in millimeters), FMD percentage of change, and nitroglycerin percentage of change did not differ at baseline,

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Abbreviations: FMD, flow-mediated dilation.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

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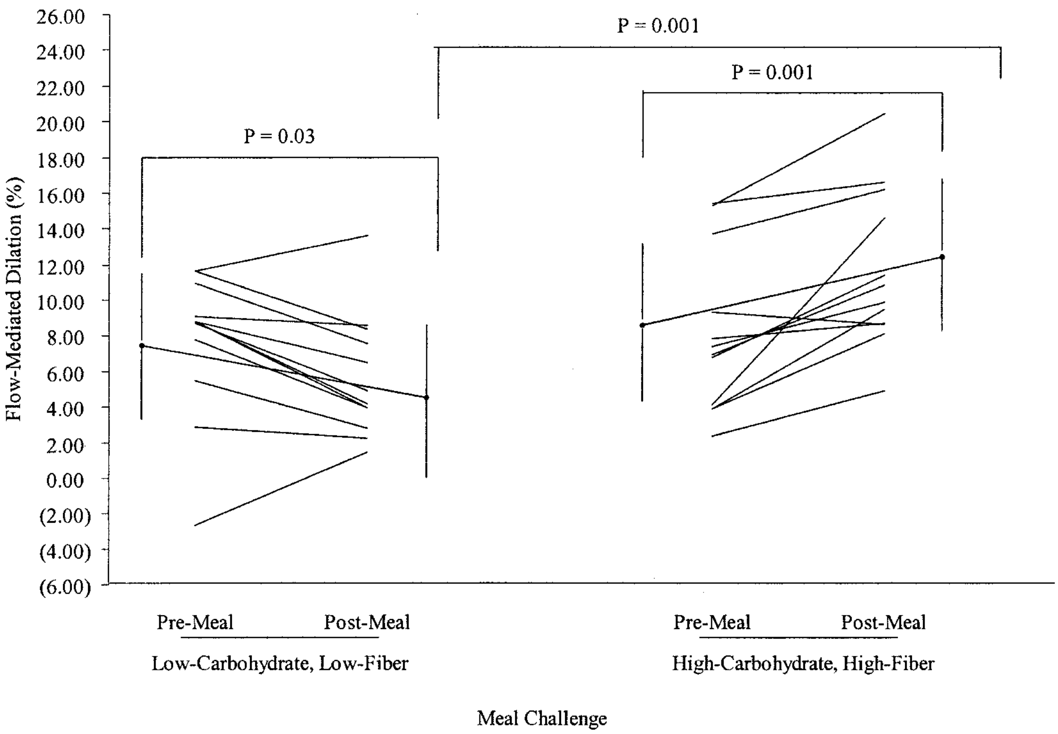

Figure 1—*Brachial artery FMD at baseline and 4 h after ingestion of low-carbohydrate and high-carbohydrate high-fiber meals in subjects with the metabolic syndrome* (n = *12*).

before administration of the two meal challenges (3.23 ± 0.64 vs. 3.25 ± 0.67 mm, $P = 0.67$; FMD 7.65 ± 4.09 vs. 8.46 ± 4.54%, $P = 0.66$; and nitroglycerin 20.89 ± 7.06 vs. 22.68 ± 5.24%, $P = 0.41$, for the low- and high-carbohydrate meals, respectively). The high-carbohydrate, high-fiber meal significantly improved FMD from 8.46 ± 4.54 to 11.87 ± 4.42% ($P = 0.001$); the low-carbohydrate meal significantly decreased FMD from 7.65 ± 4.09 to 5.69 ± 3.43% ($P = 0.03$) (Fig. 1). No differences were observed for the nitroglycerin response for either meal challenge.

CONCLUSIONS— To our knowledge, the present data are the first to show a significant positive effect of a high-fiber, mixed meal on endothelial function in subjects with the metabolic syndrome. This is consistent with data showing positive associations between increased cereal consumption and reduced risk of cardiovascular disease, the metabolic syndrome, and markers of systemic inflammation (9–13). Insoluble fiber–rich wheat bran, with its considerable antioxidant properties (17), may be a key factor in this relationship (9).

The low-carbohydrate meal significantly reduced FMD to approximately <6%, and the high-carbohydrate, high-fiber meal markedly increased FMD to nearly 12%. To provide a context for the potential importance of changes of FMD observed with these meal challenges, a study of patients with cardiovascular disease undergoing percutaneous coronary intervention with stenting demonstrated a sevenfold higher rate of restenosis in individuals with FMD <7% compared with those with FMD >7% (18). In patients with peripheral artery disease, risk of a postoperative cardiovascular event (excluding events within 30 days of surgery) was approximately nine times higher in patients with FMD <8.1% compared with patients with FMD >8.1% (2). Therefore, changes of the magnitude seen with these acute meal challenges, if sustained over time, may be of clinical importance.

Consumption of cereal fiber has consistently been associated with positive health outcomes (9–13). In as much as both endothelial dysfunction and the metabolic syndrome are markers for increased cardiovascular disease risk, cereal fiber–rich meals may improve clinical outcomes in metabolic syndrome subjects.

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