Dietary Hydroxypropyl Methylcellulose Increases Excretion of Saturated and Trans Fats by Hamsters Fed Fast Food Diets

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ABSTRACT: In animal studies, hydroxypropyl methylcellulose (HPMC) intake results in increased fecal fat excretion; however, the effects on dietary saturated fatty acids (SATs) and *trans*-fatty acids (TRANS) remain unknown. This study investigated the effect of HPMC on digestion and absorption of lipids in male Golden Syrian hamsters fed either freeze-dried ground pizza (PZ), pound cake (PC), or hamburger and fries (BF) supplemented with dietary fiber from either HPMC or microcrystalline cellulose (MCC) for 3 weeks. We observed greater excretion of SATs and TRANS by both diets supplemented with HPMC or MCC as compared to the feed. SAT, TRANS, and unsaturated fatty acids (UNSAT) contents of feces of the PZ diet supplemented with HPMC were 5−8 times higher than diets supplemented with MCC and tended to be higher in the PC- and BF-HPMC supplemented diets as well. We also observed significant increases in fecal excretion of bile acids (2.6−3-fold; $P < 0.05$), sterols (1.1−1.5-fold; $P < 0.05$), and unsaturated fatty acids (UNSAT, 1.7−4.5-fold; $P < 0.05$). The animal body weight gain was inversely correlated with the excretion of fecal lipid concentrations of bile acids ($r = -0.56$; $P < 0.005$), sterols ($r = -0.48$; $P < 0.005$), SAT ($r = -0.69$; $P < 0.005$), UNSAT ($r = -0.67$; $P < 0.005$), and TRANS ($r = -0.62$; $P < 0.005$). Therefore, HPMC may be facilitating fat excretion in a biased manner with preferential fecal excretion of both TRANS and SAT in hamsters fed fast food diets.

KEYWORDS: HPMC, dietary fibers, fecal lipids, cholesterol lowering, hamsters

■ INTRODUCTION

The prevalence of overweight and obesity has become a worldwide epidemic. Obesity is a major risk factor for noncommunicable diseases such as cardiovascular disease (CVD), noninsulin-dependent diabetes mellitus, dyslipidemia, hypertension, and cancer.[1] It is the result of a chronic positive energy balance, a sedentary lifestyle often coupled with the overconsumption of high-energy density foods. Dietary saturated fatty acids (SATs) and *trans*-fatty acids (TRANS) have also been implicated in increasing the risk of CVD through elevation of the level of serum total and low-density lipoprotein (LDL) cholesterol levels.[2,3] SAT fats found in human diets are typically derived from meat, dairy products, and eggs, while TRANS fats come primarily from commercially baked goods. Dietary fibers have been shown to lower the risk of CVD by reducing the absorption of dietary fat and cholesterol.[4] A recent study has shown that each 10 g/day increase in dietary fiber intake lowers the risk of coronary events by 12% and coronary deaths by 19%.[5]

The hypocholesterolemic and hypoglycemic effects of hydroxypropyl methylcellulose (HPMC) are well established in several animal species as well as in humans.[6−9] In addition, HPMC-supplemented diets have shown a positive effect in regulating adipocytokine production.[10] While HPMC is structurally similar to naturally occurring soluble fibers such as psyllium and β-glucan in that they are polysaccharides, HPMC unlike most natural polymers is not fermentable by colonic bacteria.[8] Although the mechanism by which HPMC lowers cholesterol remains unclear, animal studies have demonstrated increases in fecal excretion of bile acids and neutral sterols and significant differences

in patterns of hepatic expression of genes regulating sterol and bile acid metabolism.[11−13] HPMC seems to interrupt the enterohepatic bile acid circulation in the intestine by forming a physical barrier to absorption of bile acids, sterols, and glucose in the intestine.[14]

The aim of this study was to elucidate the effect of HPMC on fecal fat excretion, particularly of SAT and TRANS fats since they are known to upregulate plasma cholesterol, from hamsters fed diets based on representative Western fast foods.[7−9] Accordingly, the Golden Syrian hamster was chosen because of its well-established similarities to humans in lipoprotein profile and bile acid metabolism.[15,16] In addition, the effects of HPMC on plasma and liver cholesterol levels were determined and correlated with body weight, organ weight, and bile acid excretion.

■ MATERIALS AND METHODS

Hamsters and Diets. Thirty-one day old male Golden Syrian hamsters with a starting body weight of between 80 and 90 g (LVG strain, Charles River, Wilmington, MA) were allowed to acclimate to the animal facility and were fed commercial rodent chow (Ralston Purina, St. Louis, MO) and water ad libitum for 1 week prior to the initiation of the experimental diets. Hamsters were housed individually in wire-bottom cages in a room maintained at 20−22 °C and 60% relative humidity. A 12 h alternating light−dark cycle was maintained.

Table 1. Energy and Macronutrient Composition of the Diets

diet	PZ	PC	BF
ingredient (g/kg diet)			
fast food	918	814	920
casein	0	98	0
HPMC/MCC	38	34	38
corn oil	0	17	9
mineral mix	34	29	32
vitamin mix	9.5	8.5	9.2
approximate nutrient composition (g/kg)[a]			
fat	125	284	281
protein	167	173	178
fiber	79	37	71
carbohydrate	584	462	418
total wt (g)	955	956	947
calories/g	4.1	5.1	4.9
cholesterol	0.147	1.41	0.287
measured fat composition (mg/g)[b]			
SAT (mg/g)	46	128	73
UNSAT (mg/g)	44	105	147
SAT/UNSAT ratio	1.0	1.2	0.5
SAT + UNSAT	90	233	220
TRANS (mg/g)	2.8	7	13

[a] Calculated composition based on the manufacturer's nutrition information. [b] Composition determined by FAME analysis.

Figure 1. Body weight gain in hamsters in each diet group (PZ, PC, and BF) supplemented with either 4% MCC or 4% HPMC. Values are means ± SEMs, $n = 10$ hamster. *$P < 0.05$ as compared with the corresponding control group.

After acclimatization, hamsters were weighed and randomized into six diet groups of 10 hamsters each, consisting of three control groups fed diets containing 4% w/w microcrystalline cellulose (MCC; Dyets, Bethlehem, PA) and three "treatment" groups fed diets supplemented with 4% w/w very high viscosity HPMC (The Dow Chemical Co., Midland, MI) for 3 weeks. Diets were comprised of pizza (PZ), pound cake (PC), and hamburger and fries (BF), which had been freeze-dried, ground, and combined with vitamin mix, mineral mix, and other ingredients as shown in Table 1. To have a balanced diet composition based on guidelines provided in the American Institute of Nutrition (AIN)-93, the PC diet was supplemented with casein (98 g/kg) to reach the recommended protein content of 12−18%. In these diets, the source of fats was mainly dairy fats for both PZ and PC, while tallow and vegetable oils are the major sources for BF. Additionally, both PC and BF diets were supplemented with corn oil to increase the linoleic acid (18:2) level to 12 g/kg, which is the minimum recommended for rodents.[17] The composition of fat in the individual food diets was determined by fatty acid methyl ester (FAME) analysis (Table 1). The PZ diet contained the least amount of fat, 10.9 (w:w) or 13% fat calories. The PC and BF diets contained 24.6% fat or 30% fat calories and 24.1% fat or 30% fat calories, respectively. The total amounts of energy per gram of diet for PZ, PC, and BF were 4.1, 5.1, and 4.9 calories/g, respectively. Body weights were recorded weekly, and food intake was monitored twice per week. The study was approved by the Animal Care and Use Committee, Western Regional Research Center, U.S. Department of Agriculture (Albany, CA).

Fecal, Plasma, and Tissue Collection. Feces were collected for 3 consecutive days immediately prior to the end of the study. Fecal samples were lyophilized, milled, and stored at −20 °C. Hamsters were feed deprived for 12 h and anesthetized with isoflurane. Blood samples were collected by cardiac puncture, and ethylenediaminetetraacetic acid (EDTA) plasma samples were obtained after centrifugation at 2000g for 30 min at 4 °C and were analyzed immediately for lipoprotein content or
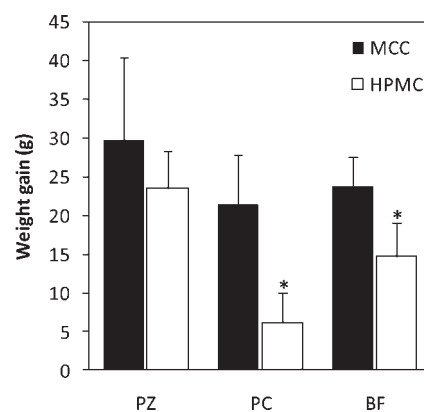
stored at −80 °C until analysis. Abdominal adipose and livers were collected, weighed, and immediately frozen in liquid nitrogen for analysis.

Plasma Biomarker Analysis. Plasma triacylglyceride (TAG), total cholesterol (TC), and free cholesterol (FC) were determined by enzymatic colorimetric assays using a Roche Diagnostics/Hitachi 914 Clinical Analyzer with assay kits (Roche Diagnostics, Indianapolis, IN, and Diagnostic Chemicals, Oxford, CT). Lipoprotein cholesterol concentrations [HDL-cholesterol (HDL-C), LDL-cholesterol (LDL-C), and VLDL-cholesterol (VLDL-C)] were determined by size-exclusion chromatography as previously described.[10] Plasma concentrations of adiponectin and insulin of feed-deprived hamsters were determined using mouse adiponectin (B-Bridge International, Sunnyvale, CA) and ultrasensitive rat insulin (Mercodia Inc., Winston Salem, NC) immunoassay kits.[10] Blood glucose concentrations in feed-deprived hamsters were measured in tail vein samples using a OneTouch Ultrameter (Johnson and Johnson, Milpitas, CA).

Hepatic Lipid Analysis. Lyophilized ground liver samples were extracted using an accelerated solvent extractor (Dionex, Sunnyvale, CA) at 100 °C, ~13.8 MPa, with 75/25 hexane/2-propanol. The sample extract was analyzed on a Roche Diagnostic/Hitachi 914 clinical analyzer (Roche Diagnostics) to measure hepatic TAG, TC, and FC using the assays described above. The percent total lipid was determined gravimetrically using the sample extract.

Fecal Lipids Analysis. The fecal lipids were extracted on a Dionex accelerated solvent extractor using a mixture of hexane and 2-propanol (3:2, v/v, 2% acetic acid) at 15 MPa and 60 °C for 30 min. The fecal lipid extracts were divided into two aliquots. One aliquot was analyzed for SAT and unsaturated (UNSAT) fatty acid composition by GC separation. Briefly, the acylglycerides and free fatty acids in the lipid extract were methylated by boron trifluoride-methanol after hydrolysis with potassium hydroxide-methanol.[18] The FAMEs were analyzed by gas chromatography using an Agilent 6890 series GC equipped with a flame ionization detector (FID) and a DB-23 analytical column (Agilent, Palo Alto, CA). The initial oven temperature was set at 200 °C and held for 5 min, then raised to 250 at 5 °C/min, and held for 5 min. A calibration solution was prepared to contain 2 mg/mL of each of the methyl esters of palmitate (C16:0), stearate (C18:0), oleate (C18:1), linoleate (C18:2), and linolenate (C18:3) and 11 μg/mL methyl erucate (Nu-Chek Prep, Elysian, MN) in heptane. The second aliquot was analyzed for total bile acids and sterols using a modified liquid chromatography method.[13] Total SAT is the sum of C14:0 through C24:0 with the predominant SATs being C16:0 and C18:0. Total UNSAT comprise the sum of cis and trans monounsaturated and polyunsaturated fatty acids C14:1 through C22:1, C18:2, and C18:3 with the dominant UNSAT being C18:1.

Table 2. Anthropometrics, Plasma Lipid, and Hepatic Lipid Concentrations in Male Hamsters Fed PZ, PC, and BF Supplemented with Either 4% MCC or 4% HPMC[a]

| | PZ | | | | PC | | | | BF | | | |
| | MCC | | HPMC | | MCC | | HPMC | | MCC | | HPMC | |
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
anthropometric data												
food intake (g/day)	6.5	0.7	6.0	0.3	7.4	0.6	7.5	1.0	7.0	0.5	7.1	1.0
calories intake (kcal/day)	27	3	25	1	38	3	38	5	34	3	35	5
food efficiency ratio	5.2	1.4	4.3	1.8	2.7	0.7	0.8*	0.5	3.3	0.5	2.0*	0.5
adipose tissue (g)	2.2	0.4	2.0	0.6	2.1	0.4	1.5*	0.3	2.0	0.4	1.5*	0.4
liver weight (g)	5.4	0.9	4.1*	0.5	5.3	0.5	3.4*	0.6	4.9	0.6	4.0*	0.3
plasma lipids												
TC (mg/dL)	188.8	16.2	131.3*	12.7	490.2	176.3	189.5*	24.9	136.4	12.0	104.3*	11.1
LDL-:HDL-C ratio	0.12	0.02	0.17*	0.05	0.25	0.05	0.14*	0.05	0.18	0.04	0.19	0.08
TAG (mg/dL)	199.3	49.6	101.2*	13.7	1019.6	345.6	194.0*	94.0	106.2	22.6	101.2	24.0
plasma biomarkers												
fasting glucose (mM)	11.0	2.1	10.1	2.7	11.0	2.4	11.5	2.5	10.4	2.0	10.6	1.8
fasting insulin (mU/L)	29.8	26.3	31.2	54.6	8.5	5.6	4.3*	2.9	8.0	4.4	8.7	6.0
adiponectin (μg/mL)	23.8	4.8	24.1	6.4	32.3	6.2	36.6	9.7	27.3	6.7	22.7	5.3
hepatic lipids												
percent total lipid (g/100 g)	16.0	1.2	17.9	0.9	22.9	2.0	18.0*	1.3	15.6	1.1	17.6	7.1
TAG (mg/g)	20.7	7.6	27.3*	4.8	25.3	6.2	22.0	6.6	17.0	5.4	29.4*	9.0
TC (mg/g)	10.5	2.7	8.3	1.1	41.7	5.5	16.9*	5.5	8.3	1.0	7.7	0.6
FC (mg/g)	6.3	0.8	5.9	0.4	9.1	0.8	6.9*	0.7	5.9	0.5	5.8	0.4

[a] Values are means ± SDs, $n = 10$. *Different from MCC, $P < 0.05$.

The total TRANS is the sum of C16:1, *trans*-C18:1, *cis,trans*-C18:2, and *trans*-C20:1.

Statistical Analysis. All data are expressed as means ± SDs unless otherwise specified. Statistical evaluation of the results was performed using JMP 7.0.2 (JMP statistical program, SAS Institute). One-way analysis of variance was performed to investigate the effect of test diets on lipid levels, fecal fat excretion, plasma biomarkers, and body and tissue weights. Statistically significant differences between control and test diets were obtained by mean value comparisons using Student's *t* test. Significance was defined at $P < 0.05$.

■ RESULTS

Weight Gain, Feed Intake, and Hepatic and Plasma Lipids. The body weight gain was significantly less in the PC- and BF-HPMC groups than in the corresponding MCC groups despite similar food intake, resulting in a 70 and 39% lower food efficiency ratio (Figure 1 and Table 2). Although not significant ($P = 0.063$), the PZ-HPMC showed a 17% reduction in body weight gain as compared to the PZ-MCC group. Furthermore, supplementation of PZ, PC, and BF with HPMC elicited a significant ($P < 0.05$) reduction in liver weight than in the corresponding control groups by 24, 36, and 18%, respectively. The retroperitoneal adipose weight in the PC- and BF-HPMC groups tended to be ∼26% lower than in the corresponding MCC groups. In the PZ-, PC-, and BF-HPMC groups, the plasma TC was significantly reduced by 30, 61, and 24%, respectively, as compared to the corresponding MCC groups ($P < 0.05$) (Table 2). In the PC-HPMC group, plasma LDL- and VLDL-C concentrations were 50 and 84% lower, respectively, than in the PC-MCC group ($P < 0.05$) (Figure 2). HPMC supplementation in the PC diet significantly lowered the LDL-C:HDL-C ratio ($P < 0.05$). The plasma TAG concentration was 49 and 38% lower in the PZ- and PC-HPMC groups than in the respective MCC groups. In addition, hepatic total lipid, TC, and FC concentrations declined by 21, 59, and 24%, respectively, in the PC-HPMC group as compared with the PC-MCC group ($P < 0.05$) (Table 2). In the PZ-HPMC group, the hepatic TC concentration was reduced by 21% than in the control groups ($P < 0.05$). Although not significant ($P = 0.077$), the BF-HPMC showed a 7% reduction in hepatic TC as compared to the BF-MCC group.

Plasma Glucose, Insulin, and Adiponectin Concentrations. The effect of HPMC-supplemented diet on glucose homeostasis was also examined in the present study. The plasma glucose and insulin concentrations did not differ between the MCC and HPMC groups for both PZ and BF groups, following feed deprivation (Table 2); however, significant reduction in insulin concentration was observed for PC-HPMC group. The plasma adiponectin concentration was 13% greater in the PC-HPMC group than in the PC-MCC group ($P = 0.12$).

Fecal Lipids. The effect of HPMC consumption on the concentrations of SAT, UNSAT, and TRANS fats of the total fecal fats were determined. The addition of HPMC to the diets caused significantly greater fecal excretion of bile acids, sterols, SAT, UNSAT, and TRANS ($P < 0.05$) as compared with the corresponding MCC groups except fecal sterol in PC diets (Table 3). Excretion of total bile acids was significantly increased 3-, 3-, and

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2.6-fold by HPMC supplemented into PZ, PC, and BF, respectively ($P < 0.05$). Fecal sterol excretions were 1.4- and 1.5-fold higher for the PZ- and BF-HPMC groups, respectively.

Excretion of SAT was significantly increased by 5.8-, 1.9-, and 2.2-fold in PZ-, PC-, and BF-HPMC, respectively, as compared with the respective MCC group ($P < 0.05$). Similarly, UNSAT excretions were significantly increased by 4.5-, 1.7-, and 2.4-fold in the PZ-, PC-, and BF-HPMC groups, respectively, as compared to the corresponding control group ($P < 0.05$). In addition, TRANS excretions were significantly increased by 7.5-, 2.7-, and 3.5-fold in the PZ-, PC-, and BF-HPMC
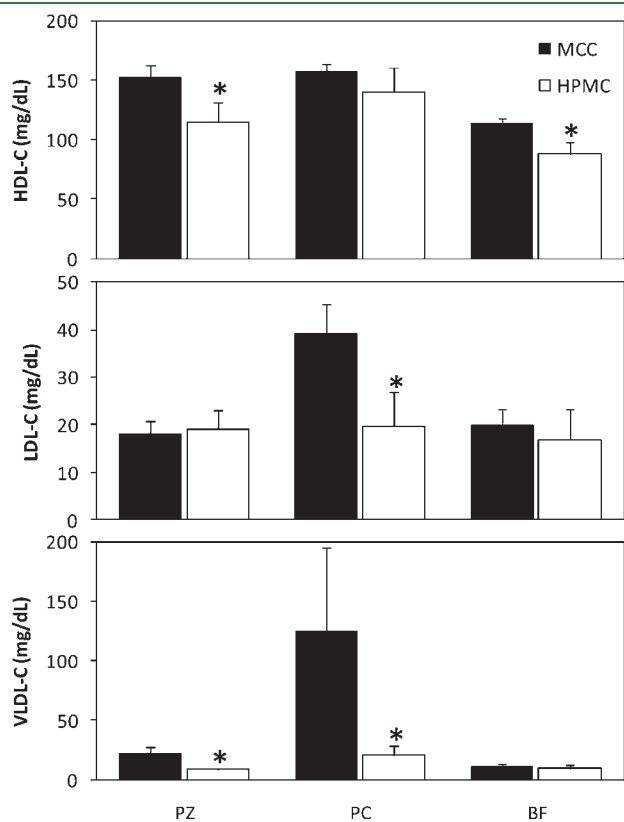

Figure 2. Lipoprotein cholesterol (HDL-C, LDL-C, and VLDL-C) concentrations in hamsters in each diet group (PZ, PC, and BF) supplemented with either 4% MCC or 4% HPMC after 3 weeks of treatment. Values are means ± SDs, $n = 10$ hamster. *$P < 0.05$ as compared with the corresponding control group.

groups, respectively, as compared to the corresponding MCC group ($P < 0.05$).

Correlation between Plasma Cholesterol and Fecal Bile Acid and Sterol Concentrations. Correlations of tissue and body weight, plasma cholesterol, and fecal fats levels were examined to elucidate the relationships between fat absorption and lipid concentrations. The increases in fecal excretions of bile acids, sterols, SAT, UNSAT, and TRANS fats are negatively correlated with liver and adipose weights and body weight gain Table 4. This reflects the reduced fat absorption by HPMC, which leads to reduced fat and cholesterol accumulation in adipose and liver, respectively. There were significant positive correlations between liver weight with plasma TAG ($r = 0.39$, $P < 0.01$), plasma FC ($r = 0.36$, $P < 0.01$), and plasma TC ($r = 0.38$, $P < 0.01$) concentrations. Moreover, the liver weights were positively correlated with VLDL-C ($r = 0.37$, $P < 0.01$), LDL-C ($r = 0.28$, $P < 0.05$), and HDL-C ($r = 0.37$, $P < 0.01$) concentrations. In addition, plasma TC concentrations were negatively correlated to fecal bile acid concentrations ($r = -0.33$, $P < 0.05$).

The overall improvement of plasma and liver lipids by HPMC was further investigated by analyzing the correlations between hepatic and fecal lipid levels for animals fed PC. Negative correlations between hepatic total percent lipids and fecal bile acids ($r = -0.88$, $P < 0.0001$), SAT ($r = -0.80$, $P < 0.0001$), UNSAT ($r = -0.73$, $P < 0.001$), and TRANS ($r = -0.80$, $P < 0.0001$)

Table 4. Correlations between Tissue Weight and Fecal Fats in Hamsters Fed 4% MCC and HPMC Diets for 3 Weeks[a]

	r		
fecal lipids	liver weight	adipose weight	body weight gain
bile acids	−0.52*	−0.52*	−0.56*
sterols	−0.34*	−0.38*	−0.48*
SAT	−0.56*	−0.42*	−0.69*
UNSAT	−0.52*	−0.47*	−0.67*
TRANS	−0.56*	−0.54*	−0.62*
plasma TAG	0.39*	−0.12	0.05
plasma FC	0.36*	−0.08	0.01
plasma TC	0.38*	−0.08	0.08
plasma VLDL-C	0.37*	−0.11	0.07
plasma LDL-C	0.28*	−0.17	0.10
plasma HDL-C	0.37*	0.31*	0.14

[a] Values are Pearson correlations, $n = 10$. *$P < 0.01$.

Table 3. Fecal Bile Acids, Sterols, SATs, UNSAT, and TRANS Excretion in Hamsters Fed PZ, PC, and BF Diets Supplemented with Either 4% MCC or 4% HPMC[a]

	PZ				PC				BF			
	MCC		HPMC		MCC		HPMC		MCC		HPMC	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
bile acids (mg/g)	1.7	0.6	5.1*	2.0	3.9	1.2	11.8*	2.6	6.4	1.6	16.5*	9.2
sterols (mg/g)	8.1	1.3	11.6*	3.6	15.3	1.9	16.4	2.3	16.7	3.3	24.3*	6.7
SAT (mg/g	10.7	7.1	61.7*	14.4	107.9	36.1	202.8*	21.9	55.6	50.8	120.1*	32.9
UNSAT (mg/g)	2.9	2.1	13.1*	3.0	19.7	5.3	34.3*	8.2	13.5	9.2	32.8*	11.4
SAT/UNSAT ratio	3.5		4.7		5.5		6.2		3.9		3.8	
TRANS (mg/g)	0.6	1.4	4.5*	1.4	5.0	1.8	13.4*	4.9	4.2	3.5	14.7*	7.3

[a] Values are means ± SDs, $n = 10$. *Different from MCC, $P < 0.05$.

were observed. Furthermore, there were negative correlations between hepatic TC concentrations and fecal bile acids ($r = -0.93$, $P < 0.0001$), SAT ($r = -0.84$, $P < 0.0001$), UNSAT ($r = -0.68$, $P < 0.001$), and TRANS ($r = -0.82$, $P < 0.0001$).

■ DISCUSSION

In a 15 year prospective, the CARDIA study of over 3000 subjects reported a strong association between fast food consumption and obesity and insulin resistance.[5] Moreover, a meta-analysis of 16 large cross-sectional studies, seven prospective studies, and three experimental studies indicated that increased caloric intake due to fast food consumption was linked to obesity even though other factors including physical activity, overall eating patterns, gender, age, or total caloric intake represent significant confounding effects.[19] In this study, we investigated the impact of a viscous soluble dietary fiber, HPMC, on physiological characteristics related to metabolic diseases in male hamsters fed diets containing two of the most popular fast foods (PZ and BF) and a high-fat bakery product (PC) that are high in fat, particularly saturated fats.

This study confirms the consistently reported lipid-lowering effect of HPMC, including reductions in plasma TC in humans and hamsters.[8−10] Plasma cholesterol in this strain of hamsters on a chow diet is about 80 mg/dL.[20] In this study, hamsters on the three diets supplemented with MCC for 3 weeks were hypercholesterolemic with plasma TC levels of 136−490 mg/dL. In the same diets supplemented with HPMC, significant reductions in plasma TC were observed, as compared to the corresponding control diet. The magnitude of the hypocholesterolemic effect, ranging from 20 to 40% reduction with 2−8% HPMC consumption, is consistent with findings from a number of studies using hamster as an animal model.[10,11] In hamster and other rodents, cholesterol is transported primarily by HDL, and so, it was not surprising to find that on a percentage basis most of the TC reduction in PZ and BF was due to reductions in HDL. Also, hamsters and humans, but not mice and rats, have plasma cholesteryl ester transfer protein (CETP) that can move cholesterol from HDL to VLDL and LDL. The PC and PZ diets contain about 18 and 9% saturated fat mainly from butter, and the BF diet is about 8% saturated fat. The high levels of both total and SAT fats of the PC diet are probably the cause of its extremely high VLDL level as compared to PZ with the same fat profile but low total fat level and the BF diet with the same total fat level but about half the SAT fat content.

The most commonly suggested mechanism for the hypocholesterolemic effect of HPMC is interference with intestinal cholesterol absorption and bile acid equilibrium, leading to an increase in fecal neutral sterol and bile acid excretion.[13] In this study, our data confirm and extend these previous findings. The hypercholesteremia induced by the fast foods diets was reduced by replacement of MCC, an insoluble dietary fiber with the highly viscous soluble fiber, HPMC, while maintaining the same level of total fat, saturated fat, and cholesterol in the diet. Moreover, the plasma TC reduction by HPMC is positively correlated with decreases in hepatic TC levels ($r = 0.844$, $P < 0.01$). Therefore, supplementation of HPMC seems to improve the overall cholesterol metabolism by removing plasma cholesterol through the LDL receptor when hepatic cholesterol concentration is low, as we have previously shown.[11] In previous studies, increases in circulating adiponectin concentrations by HPMC in 4−8 weeks of feeding period were linked to the increase

of hepatic fatty acid oxidation and the decrease of fatty acid synthesis, which in turn reduced the TAG concentrations in hamster liver.[10,11] In this study, no significant changes in adiponectin were observed by HPMC; thus, hepatic TAG levels were not affected by HPMC intake.

Enhanced excretion of bile acids was observed when HPMC was supplemented in the three diets. The excretion of bile acids and the depletion of the bile acid pool are important mechanisms of plasma cholesterol lowering, which has been extensively studied. A previous study has shown that the hepatic bile acid and cholesterol metabolism was mediated by HPMC intake, which was associated with the decreased bile acid concentrations in the enterohepatic circulation.[11] Additionally, bile acids also participate in the emulsification and enzymatic hydrolysis of fat in the intestinal lumen, and on the basis of this study, we propose that HPMC interacts with bile acids in the intestinal lumen resulting in higher total fat excretion, saturated fat excretion, and *trans* fat excretion as well as bile acid excretion. The significant negative correlations between the body weight gain and the fecal lipids further supports that the reduced fat absorption due to HPMC intake leads to lower body weight gain.

Hamsters fed fast food diets supplemented with HPMC excreted significantly higher levels of total fecal fat, SAT, UNSAT, and TRANS as compared to MCC. The consumption of high levels of cellulose has also been shown to decrease intestinal fat absorption although the fatty acid composition was not characterized.[21] In this study, total fecal SAT excretion was greater than UNSAT in all of the diets regardless of diet types. This may be in part due to the fact that long chain SAT are less soluble and are absorbed as efficiently as UNSAT.[22] However, the ratio of SATs to UNSAT fatty acids (SAT/UNSAT ratio) in the nutrient composition of PZ, PC, and BF ranged from 0.5 to 1.3. In the feces, this ratio ranged from 3.5 to 6.2. Therefore, there is a 3−8-fold enrichment of SAT depending upon the fast food component of the diet. The excretion of more SAT than UNSAT was observed for both MCC and HPMC diets. However, the increment of SAT depletion was greater with HPMC than with MCC. In addition, the fast food-based diets containing HPMC fiber increased fecal TRANS excretion in all of the experimental diets as compared to MCC ($P < 0.001$). The mechanism by which HPMC affects SAT, UNSAT, and TRANS removal is not clear. The preferential enhancement of saturated and *trans* fats excretion may be due to the similarity of the structures and melting points between these two types of fatty acids, which is important in the process of intestinal absorption. Several possible mechanisms whereby the effective soluble dietary fibers may influence lipid absorption include intralumenal disruption of micellar solubilities of lipids, altered diffusibility of bulk and monomolecular forms of lipids, reduced transport into the mucosal surface transport barrier, and decreased exocytosis of lipids.[23]

In summary, these findings demonstrate that HPMC, a viscous soluble dietary fiber, may be facilitating fat excretion in a biased manner with preferential fecal excretion of both SATs and TRANS, in addition to the increased fecal bile acid and neutral sterol excretion. Excretion of bile acids, neutral sterols, SATs, and TRANS may all contribute to the cholesterol-lowering effect by HPMC. These results indicate that HPMC reduces lipid absorption and lipolysis in the gastrointestinal tract, which in turn reduced body weight gain for hamsters fed a fast food/high fat diet. This study further supports the potential dietary use of HPMC for the prevention or management of dyslipidemia-related diseases such as CVD and obesity.

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