Human Nutrition and Metabolism

Apparent Mineral Retention Is Similar in Control and Hyperinsulinemic Men after Consumption of High Amylose Cornstarch$^{1,2}$

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ABSTRACT The effects on apparent mineral retention after long-term consumption of a high amylose diet containing 30 g resistant starch (RS) were investigated in 10 control and 14 hyperinsulinemic men. Subjects consumed products (bread, muffins, cookies, corn flakes and cheese puffs) made with standard (70% amylopectin, 30% amylose; AP) or high amylose (70% amylose, 30% amylopectin; AM) cornstarch for two 14-wk periods in a crossover pattern. Starch products replaced usual starches in the habitual diet for 10 wk followed by 4 wk of consuming the controlled diets. During wk 12, all urine, feces and duplicate foods were collected for 7 d. Urinary chromium losses after a glucose tolerance test or 24-h collections of the hyperinsulinemic and control subjects did not differ and were not altered by diet. Except for zinc, the two subject types did not differ significantly in apparent mineral balance. Apparent retentions of calcium and magnesium were not significantly affected by diet (AM vs. AP) or type-by-diet interaction. Apparent iron retention tended to be greater after AM than AP consumption ($P < 0.09$). Apparent copper retention was greater after consuming AP than after AM ($P < 0.02$), whereas apparent zinc retention was greater after consuming AM than after AP ($P < 0.018$). Zinc also showed a significant type-by-diet interaction ($P < 0.034$) with control subjects retaining less zinc after consuming AP than after AM. In summary, a high amylose cornstarch diet containing 30 g RS could be consumed long term without markedly affecting, and possibly enhancing, retention of some minerals. J. Nutr. 132: 1886–1891, 2002.

KEY WORDS: • amylose • resistant starch • hyperinsulinemia • minerals • chromium • humans

Diet high in complex carbohydrates, especially those slowly digested (i.e., low glycemic index) or those not digested in the small intestine [fiber and resistant starch (RS)]$^4$, have been recommended as a means of reducing insulin response and/or lipids levels in individuals who are diabetic, hyperlipidemic or carbohydrate sensitive (1–3). The development of foods high in RS has been suggested as a means to increase unavailable carbohydrate intake (4). Resistant starch appears to function like both insoluble and soluble fiber in the intestine; it is not digested in the small intestine, like the insoluble fibers, but is digested by colonic bacteria, like the soluble fibers (5). In general, total carbohydrates contribute 40–60% of the energy intake for most populations, but the type of carbohydrate varies greatly with the diet consumed. The potential exists for increasing the amount of unavailable or “RS” reaching the colon through the use of retrograded or chemically modified starch added to commercial foods. Increasingly, reduced-fat foods, containing modified starches and/or increased soluble fiber, are being manufactured and used to reduce total dietary fat intake (6).

High intakes of dietary fiber may result in net mineral loss, particularly when a single fiber source was used to achieve the high fiber diet (7–9). Decreased transit time could also contribute to decreased mineral absorption in the small intestine (7). Increased apparent retentions of calcium and magnesium (10,11) as well as no effect (7–9) have been reported when nutrients readily digested in the colon have been consumed as part of the diet. The short-term consumption of transgalactooligosaccharides (9 d) or fructooligosaccharides (5 wk) as an unavailable carbohydrate source increased calcium (10) or magnesium (11) absorption in postmenopausal women. Calcium and magnesium apparent absorptions were not different after men consumed raw or retrograded high amylose starch for 1 wk (12). In contrast, rats had greater apparent absorptions of calcium and magnesium after they were fed raw, but not retrograded starch (13,14).

Short-term addition of food items containing an average of 39 g RS/d for 3 wk (15) or 17–25 g RS/d for 4 wk (16) to the self-selected diets of women and men decreased pH and significantly increased short-chain fatty acids (SCFA). Microbial fermentation of RS sources (potato starch or high amylose

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4 Abbreviations used: AM, 70% amylose/30% amylopectin starch; AP, 70% amylopectin/30% amylose starch; HI, hyperinsulinemic subjects; RS, resistant starch; SCFA, short-chain fatty acids.

cornstarch fed to rats for 3 wk) decreased luminal pH, which was proposed as the mechanism for the observed increase in mineral absorption (17–19). Rectal infusion of SCFA in humans, simulating colonic fermentation, has been shown to enhance calcium absorption in the distal colon (20).

It was postulated that dietary changes that could decrease insulin levels in men, especially those with elevated insulin levels, would reduce chromium losses. Increased chromium losses are related to increased intake of refined carbohydrate (21,22). The reduced insulin levels could in turn reduce urinary chromium losses. Although the short-term (≤4 wk) effect of consuming RS on apparent mineral retention has been examined, the long term (12–14 wk) effect of high amylase starch as the major carbohydrate source in the habitual diet has not been determined previously.

SUBJECTS AND METHODS

Subjects. The study was approved by the Human Studies Committees of the USDA and Georgetown University. Written informed consent was obtained from the volunteers before they participated in the study. Volunteers were not eligible to participate if they were taking drugs known to affect glucose, insulin or lipid metabolism. Those who had elevated fasting glucose or abnormal glucose levels in response to a glucose tolerance test (1 g glucose/kg body) were excluded from participating. Free-living men (n = 29) were selected for participation in the dietary intervention study. Half of the subjects selected had a normal insulin response (control subjects); the remaining subjects had a higher than normal insulin response to the same glucose load [hyperinsulinemic (HI) subjects]. Three subjects volunteering subjects had a higher than normal insulin response to the same selected had a normal insulin response (control subjects); the remaining subjects were excluded from participating. Free-living men (n = 29) were selected for participation in the dietary intervention study. Half of the subjects selected had a normal insulin response (control subjects); the remaining subjects had a higher than normal insulin response to the same glucose load [hyperinsulinemic (HI) subjects]. Three subjects voluntarily withdrew from the study, one subject was removed from the study for noncompliance, and one subject for medical reasons before dietary starch replacement had begun. Mean (range) age and weight of the 24 men who completed the study were 41 y (28–58 y) and 83.7 kg (55–115 kg). All over-the-counter or prescribed medications taken by the subjects during the study were recorded.

Diet. Subjects consumed diets that differed only in the starch source. The primary carbohydrate was either high amylase cornstarch (containing 70% of the starch as amylose, 30% as amylpectin, AM) or standard cornstarch (containing 70% amylopectin, 30% amylose, AP). The two starch types were fed in a crossover pattern with each subject consuming each starch for 14 wk. Subjects were randomly divided so that half consumed each starch during each period. Food

### Table 1

<table>
<thead>
<tr>
<th>Food Item</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakfast</td>
<td></td>
</tr>
<tr>
<td>Apple juice</td>
<td>203 g</td>
</tr>
<tr>
<td>Corn flakes2</td>
<td>57 g</td>
</tr>
<tr>
<td>Milk, 2% fat</td>
<td>250 g</td>
</tr>
<tr>
<td>Bread2</td>
<td>30 g</td>
</tr>
<tr>
<td>Margarine</td>
<td>25 g</td>
</tr>
<tr>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>Tuna, water pack</td>
<td>26 g</td>
</tr>
<tr>
<td>Imitation mayonnaise</td>
<td>15</td>
</tr>
<tr>
<td>Tomato</td>
<td>51 g</td>
</tr>
<tr>
<td>Lettuce</td>
<td>25 g</td>
</tr>
<tr>
<td>Pickle, dill</td>
<td>41 g</td>
</tr>
<tr>
<td>Bread2</td>
<td>60 g</td>
</tr>
<tr>
<td>Cheese puffs2</td>
<td>51 g</td>
</tr>
<tr>
<td>Apple</td>
<td>144 g</td>
</tr>
<tr>
<td>Spice cake2</td>
<td>114 g</td>
</tr>
</tbody>
</table>

1 Average menu provided 11.65 MJ/d (2800 kcal/d).
2 Contained either high amylose or high amylpectin starch.

### Table 2

<table>
<thead>
<tr>
<th>Energy, MJ (kcal)</th>
<th>Protein, g</th>
<th>Fat, g</th>
<th>Carbohydrate, g</th>
<th>Protein, % of energy</th>
<th>Fat, % of energy</th>
<th>Carbohydrate, % of energy</th>
<th>Polyunsaturated/saturated fat ratio</th>
</tr>
</thead>
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<tr>
<td>11.65 (2796.6)</td>
<td>121.3</td>
<td>113.7</td>
<td>371.9</td>
<td>17.5</td>
<td>36.7</td>
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During the remaining 4 wk of each period, a controlled diet with a 7-d rotating menu was prepared, weighed and served in the Beltsville Human Nutrition Study Facility (Beltsville, MD). A 1-d menu is shown in Table 1. The starches, cereal, cheese puffs and chemical composition of the starches were provided by Aramark Mayo-Product Company (Hammond, IN). Controlled diets were designed to meet the Recommended Dietary Allowance (23) for the age and sex of the participants. The controlled diet contained 34% of total energy from fat, 15% from protein, and 51% from carbohydrate, calculated by using USDA Handbook No. 8 (24) (Table 2). Carbohydrate sources were either raw or cooked vegetables, raw or canned fruit, fruit juices or products made from the two starches. In addition to the five products (bread, muffin, cookie, cereal and cheese puffs) fed in the starch replacement period, spice cake, angel food cake and a chocolate “brownie type” dessert were added to the menu. Pizza, bread pudding and French toast were made with the cornstarch bread appropriate for the period. No wheat flour was used in the controlled diet.

Of the energy from carbohydrates in the diet, 55% was provided by the refined starches used in the research products. Cholesterol intake averaged 410 mg/d. The 11.67 MJ (2800 kcal) diet contained ~200 g of starch, and analysis of the total controlled diet indicated that 30 g of starch in the AM diet and 1 g in the AP diet were RS (25). Total dietary fiber levels were the same (31.9 ± 0.6 g/d in the AM diet, 33.3 ± 0.7 g/d in the AP diet) (25) when the RS fraction was solubilized with dimethyl sulfoxide and excluded from the dietary fiber determination (26,27). Resistant starch content of the five starch products used throughout the study is shown in Table 3.

Study design. The HI subjects were paired as closely as possible with control subjects by age and weight. Subjects began consuming the diets in a staggered pattern to meet the scheduling constraints of the room calorimeter during the controlled-diet period. Four subjects (two control and two HI) began the study at the same time; one control and one HI subject began to consume each diet so that each combination of diet and subject type was represented within a group. During the 4-wk controlled-diet period, morning and evening meals were consumed at the diet facility. Weekend and holiday meals and weekday lunches were packed for consumption at home or at work. Subjects' dietary energy levels were based on their initial weights unless this requirement was known from previous measurements. To

### Table 3

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<thead>
<tr>
<th>Energy, MJ (kcal)</th>
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<th>Carbohydrate, g</th>
<th>Protein, % of energy</th>
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</table>
Resistant starch content in the starch products

<table>
<thead>
<tr>
<th>Starch product</th>
<th>AM³</th>
<th>AP</th>
<th>AM</th>
<th>AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bread</td>
<td>16.7</td>
<td>0.6</td>
<td>12.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Muffin</td>
<td>10.6</td>
<td>1.5</td>
<td>4.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Cookie</td>
<td>8.3</td>
<td>1.2</td>
<td>3.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Cheese puffs</td>
<td>16.8</td>
<td>3.0</td>
<td>5.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Corn flakes</td>
<td>11.2</td>
<td>1.9</td>
<td>3.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Calculated average intake</td>
<td>29.4</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Determined by the method of Lee et al. (26).
2 Based on an average energy intake of 11.65 MJ (2796.6 kcal)/d.
3 AM, 70% of the cornstarch used to make the product was amylose and 30% amylpectin starch; AP, 70% of the starch was amylose and 30% amylpectin starch.

Apparent retention of minerals, other than chromium, was calculated as intake – (fecal + urinary excretion). The percentage of retention was calculated as 100 × [intake – (fecal + urinary excretion)]/intake.

**Statistics.** Data on physical characteristics are arithmetic means ± SEM. Mineral data are reported as least-squares means ± SEM. Data were analyzed statistically using the Mixed procedure of SAS (PC-SAS, version 6.11, SAS Institute, Cary, NC). The fixed portion of the model contained type, period, diet (starch type), and diet-by-type interaction; group, group-by-type, and subject (group-by-type) interactions were defined as random. The analysis of repeated measures used a compound symmetry covariance matrix. Because the HI subjects were selected on the basis of their insulin response, chromium data were evaluated using hierarchical analysis of covariance (30) with insulin area under the curve as the covariate. Mean comparisons were by least significant differences. The critical level of significance for all tests was set at P < 0.05.

**RESULTS**

The controlled diets were designed so that only the starch source would differ. Significantly more RS was present in the AM diet (30 vs. 1 g in the AP diet). Fecal weight at the end of the two diet periods did not differ even though the AM diet contained more fiber-like material as RS. Fecal wet weights were 269.4 ± 14.5 g/d after the AM diet period and 246.0 ± 14.5 g/d after the AP diet period, and dry weights were 43.3 ± 3.0 and 36.8 ± 3.0 g/d, respectively. Fecal starch excretion was greater after the AM diet was consumed. Starch excreted was 3.8 ± 0.7 g/d after the AM diet period and 0.8 ± 0.6 g/d after the AP diet period (P < 0.001). Transit time was 41.7 ± 2.8 h (range 13–71 h) after the AM diet period and 34.1 ± 2.7 h (range 12–61 h) after the AP diet period (P < 0.002). Control subjects consuming AM had the longest transit time (46.6 vs. 35.5 h for AP; HI subjects, 36.7 vs. 32.2 h, respectively) although the diet-by-subject-type interaction was not significant (P ≥ 0.12).

Urinary chromium excretions from 0 to 90 min or 0 to 180 min after the glucose tolerance test did not differ between the control and HI subjects (0–90 min, 0.29 and 0.37 ± 0.08 nmol, respectively; 0–180 min, 0.60 and 0.64 ± 0.12 nmol, respectively) or between dietary starch sources [0.33 and 0.34 ± 0.07 (90 min); 0.68 and 0.63 ± 0.12 (180 min) nmol; AM vs. AP, respectively]; no interaction was observed. Urinary chromium (24-h) was not significantly related to subject type, diet or the interaction of subject type with diet (control, 4.1 ± 0.9 nmol; HI, 3.9 ± 0.7 nmol; AM, 3.9 ± 0.8 nmol; AP, 4.5 ± 0.8 nmol). When insulin area under the curve was used as a covariate, a significant (P < 0.005) association was observed between chromium excretion and insulin after the starch tolerance test, but not after a glucose tolerance test, and accounted for 23% of the variance among subjects. Chromium excretion, adjusted for insulin response, tended to be lower (P ≥ 0.08) after the AM diet period (3.3 ± 0.9 nmol) than after the AP diet period (4.0 ± 0.9 nmol).

No differences in mineral intake, fecal or urinary excretion, or apparent mineral retention were observed between subject types (urinary calcium, P ≥ 0.19; magnesium, P ≥ 0.13; remaining values P ≥ 0.52); therefore, data are presented by diet. Calcium (AP, 26.3 ± 0.8 vs. AM, 25.2 ± 0.8 mmol/d; P > 0.002), copper (AP, 29.6 ± 0.9 vs. AM, 27.0 ± 0.9 mmol/d; P < 0.011), and iron (AP, 297.5 ± 8.8 vs. AM, 241.5 ± 8.8 mmol/d; P < 0.001) intakes were greater during the AM diet period than during the AP diet period, whereas magnesium (AP, 11.5 ± 0.4 vs. AM, 12.3 ± 0.4 mmol/d; P < 0.001) and zinc (AP, 158.6 ± 6.9 vs. AM, 176.0 ± 6.9 mmol/d; P < 0.006) intakes were greater during the AM diet period.
Urinary and fecal excretions of calcium, magnesium and copper were not different between the two diet periods and no diet by subject type interaction was observed. Fecal excretion of iron was higher \((P < 0.002)\) when subjects consumed the AP diet \((297.4 \pm 18.5 \text{ nmol/d})\) than when they consumed the AM diet \((234.5 \pm 18.5 \text{ nmol/d})\), reflecting the intake pattern. Fecal excretion of zinc showed a significant diet-by-type interaction \((P < 0.05)\); the fecal zinc excretion of HI subjects reflected intake and was higher during the AM \((150.8 \pm 10.4 \text{ nmol/d})\) than the AP \((137.4 \pm 10.4 \text{ nmol/d})\) diet period. However, control subjects had greater fecal zinc excretion when they consumed the AP \((137.4 \pm 12.8 \text{ nmol/d})\) than the AM \((137.4 \pm 12.8 \text{ nmol/d})\) diet, even though intake was greater during the AM diet period.

Values for retention of minerals given here are for apparent retention because they were calculated as food intake minus fecal and urinary excretion. Other mineral losses (i.e., through sweat, hair, nails or skin) were not measured; for iron, only intake minus fecal excretion was determined because little iron is lost in urine. Apparent retentions of calcium \((P \geq 0.78)\), magnesium \((P \geq 0.89)\) and iron \((P \geq 0.09)\) were not affected by the starch consumed. Apparent retention of copper was greater \((P < 0.02)\) when the AP diet was consumed compared with the AM diet. Zinc retention showed a significant diet \((P < 0.02)\) and diet-by-type interaction \((P < 0.03)\); HI subjects had similar retentions when they consumed the two diets \((13.2 \pm 12.4 \text{ and } 10.8 \pm 12.4 \text{ nmol/d, AM and AP, respectively})\), whereas the control subjects had higher retention when they consumed the AM diet \((33.8 \pm 15.5 \text{ nmol/d})\) and lower retention after the AP diet \((-7.5 \pm 15.5 \text{ nmol/d})\) than was observed after the HI subjects consumed the two diets. Retention as a percentage of intake tended to be higher for calcium \((3.5 \text{ vs. } 0.2\%\), \(P > 0.28)\) and iron \((0.9 \text{ vs. } -1.4\%, P \geq 0.09)\) after the AM than that after the AP diet was consumed. The percentage of zinc retention showed a significant diet-by-subject type interaction \((P < 0.03)\). The percentage retention of the hyperinsulinemic subjects did not differ after the two diets were consumed. However, the control subjects' retention as a percentage of intake for zinc was significantly greater after the AM diet was consumed than after the AP diet, reflecting the same pattern as apparent retention.

**DISCUSSION**

A reduced transit time, commonly observed with increased fiber consumption, was not observed here. Spiller (31) reported that transit times would not decrease appreciably when wet fecal weights exceeded 200 g/d. However, we did not expect a longer transit time after the men consumed the high AM diet, containing \(\sim 30 \text{ g of RS, compared with the time after they consumed the standard cornstarch diet. Muir et al. (32) reported lower fecal pH, but decreased fecal bulk, slower transit time and lower fecal concentration of SCFA after subjects consumed a diet for 3 wk containing 2 g RS/MJ (somewhat less than that consumed by subjects in the study reported here) compared with measurements after a diet containing 0.8 g RS/MJ. Higher intakes of RS (39 g/d for 3 wk) increased fecal weight, SCFA and nonstarch polysaccharides (15). The authors suggested that the high levels of starch reaching the colon had a sparing effect on nonstarch polysaccharides; unlike the starch, they can hold fluid, and cellular biomass can be greatly increased in the stools. SCFA in the colon have been reported to be a potent stimulus for colonic absorption of sodium and water (33). This decrease in fecal water could decrease total fecal weight even if the bacterial cell mass was increased, which was observed when soluble fiber, which includes pectin, guar gum, and oat fibers, are fermented by colonic bacteria in the large intestine (34). It has also been reported (35) that increased colonic levels of SCFA affect proximal gut motility and gastric tone. Consumption of a bolus of lactulose decreased gastric tone and increased hydrogen expiration. Intracolonic infusion of either lactulose or SCFA also decreased gastric tone with the greatest reduction occurring after the highest dose of SCFA. The authors indicated that fermentation of carbohydrate sources can reduce gastric tone and that SCFA were likely the metabolite responsible for the reduced colonic tone or "colonic brake."

Diets that used a single fiber source, such as whole-meal wheat, corn or rice, to achieve a high fiber diet were reported to result in negative balances for some minerals (calcium, magnesium and zinc) (7,8). Other studies, especially those using soluble fibers, reported no effect from added fibers (7–9). Increased calcium and magnesium apparent retentions (10,11) have been reported when nutrients readily digested in the colon have been consumed as part of the diet. The short-term consumption of transgalactooligosaccharides (9 d) or fructo-oligosaccharides (5 wk) as an unavailable carbohydrate source increased calcium (10) or magnesium (11) absorption in postmenopausal women. Studies lasting longer than 3–4 wk generally did not report significant negative balances with high fiber consumption (7–9).

High amylose cornstarch has been fed as a source of RS (raw starch or cooked and cooled starch to form retrograded amylose) to estimate mineral absorption. Heijnen et al. (12) fed 24 men glucose, raw high amylose starch (30 g type 2 RS), or retrograded high amylose starch (30 g type 2 RS) for 1 wk each. Apparent absorptions of calcium and magnesium were not significantly different after consumption of the diet containing the readily digested carbohydrate and after the two diets containing RS. Subjects in the present study had consumed a similar amount of RS as part of the high amylose diet for 12 wk when the balance collections were made. Calcium and magnesium absorptions by rats fed standard (low RS) or high amylose cooked cornstarch (retrograded RS) for 13 d were equivalent (14). Similar to the results of Heijnen et al. (12) after short-term (1 wk) consumption of a high amylose diet, chronic consumption of high amylose starch by the men also did not affect calcium or iron apparent retention compared with the standard (AP) starch.

Infant pigs fed a meal of cooked high amylose cornstarch (containing 16.4% RS) or digestible rice starch had significantly greater apparent absorptions of calcium and iron after the meal with the RS (36); no differences between the starch sources were observed for phosphorus or zinc absorption. Rats fed the raw potato starch (RS source) had significantly higher apparent absorptions of calcium and magnesium than did rats fed the standard starch. Lopez et al. (17) fed rats adapted to a digestible wheat starch (73 g/100 g) diet or a diet containing RS (20 g raw potato starch and 53 g digestible wheat starch/100 g diet) for 3 wk. The mineral retention was reported to be significantly enhanced (Ca, 46%; Mg, 50%; Zn, 33%; Fe, 20% and Cu, 61%) after the diet with RS compared with those that consumed digestible wheat alone. The addition of 20 g wheat bran to the digestible wheat diet reduced apparent mineral retention (P = 29%; Zn = 60%; Fe = 26% and Cu, 47%) compared with the digestible wheat diet (18). Apparent mineral retention in rats fed both diets containing RS was improved, similar to the previous study (P, 30%; Ca, 39%; Mg, 32%; Zn, 47%; Fe, 27%; and Cu, 37%) (18). When Lopez et al. (19) compared raw potato starch and high amylose cornstarch as the sources of RS in the wheat diet, the source of the
RS did not affect the increase in the apparent absorptions of calcium (50%), magnesium (50%), zinc (27%), iron (21%), and copper (90%). In studies with rats, Lopez et al. (17–19) concluded that the improved mineral absorption after consumption of diets containing RS was due to intestinal fermentation of the RS. The altered luminal pH had a stimulatory effect on mineral utilization, largely abolishing the inhibitory effects of phytic acid.

Heynek et al. (37) showed that lower pH reduced calcium binding in various brans used as fiber sources. Younes et al. (13) observed active fermentation, acidification of cecal contents, and increased calcium concentrations in the feces of rats fed high amylase starch compared with wheat starch. The addition of 39 g RS/d for 3 wk (15) or 17–25 g RS/d for 4 wk (16) to the self-selected diets of women and men decreased pH and significantly increased SCFA. Rectal infusion of SCFA in humans, simulating colonic fermentation, has been shown to enhance calcium absorption in the distal colon (20). Research from several investigators (13,14,38) has suggested that the lower pH present after starch fermentation increases the solubility of calcium and thereby stimulates calcium absorption. Demigné et al. (38) and Younes et al. (13) suggested that there was a shift of some calcium absorption to the large intestine and that colonic absorption made an important contribution to overall mineral balance.

Similar to soluble fibers, RS in the AM diet appears to be fermented in the colon, resulting in increased breath hydrogen (39), suggesting increased SCFA production. The acidification noted in rats (12–14,17–19,37,38) likely occurred in the colonic contents of our subjects. The enhanced mineral absorption reported in rats with low fecal or colonic pH or after RS intake could explain the greater copper, iron, and zinc apparent retentions reported here. Another explanation could be that the longer transit time observed during the high amylose diet period resulted in additional time for minerals to be absorbed.

Chromium is an essential nutrient for glucose metabolism (40,41), and inadequate chromium intake has been associated with elevated levels of glucose and insulin (41), such as observed in the hyperinsulinemic subjects. Chromium supplementation decreases circulating glucose, insulin and hemoglobin A1c in people with type 2 diabetes (41). High simple sugars diets increase urinary chromium losses (21) and urinary chromium losses increase with increases in circulating insulin in control subjects but not in hyperinsulinemic subjects (22). At low levels of circulating insulin, increased urinary chromium losses of subjects with hyperinsulinemia are also correlated with increases in circulating insulin, but urinary chromium losses reach a maximum at elevated levels of circulating insulin. Amylopectin leads to greater increases in circulating insulin than AM (42–44) and therefore may lead to increased chromium losses. Similarly, increased consumption of simple sugars compared with complex carbohydrates leads to increased circulating insulin and corresponding increases in urinary chromium losses (21). In the study reported here, we did not observe a difference in urinary chromium losses between control and hyperinsulinemic men, which is consistent with our previous results in subjects with low levels of circulating insulin (22). The differences in insulin due to the AM and AP diets did not appear to be large enough to cause significant differences in urinary chromium losses between the two groups of subjects. However, the insulin area under the curve was associated with chromium excretion and chromium losses tended to be lower (P = 0.1) during the AM diet period compared with comparable values during the AP diet period.

The enhanced absorption of some minerals observed after AM consumption does not appear to occur with chromium. However, urinary chromium excretion, which is a measure of chromium absorption, is also influenced by specific increases in urinary chromium losses and may not give a true measure of chromium absorption. Once chromium is mobilized, it is not reabsorbed by the kidneys and is excreted in the urine (41). Studies using a stable isotope of chromium to differentiate increased chromium absorption from a combination of increased absorption and excretion would be a more sensitive measure of chromium absorption (45).

Total starch intake varies greatly; industrialized countries consume approximately half the amount consumed in developing countries (46). Resistant starch intake, estimated as a fraction of total intake, varies between 3 and 20 g/d in Western countries and between 9 and 40 g/d in developing countries (46). Resistant starch intake (based on RS content of foods) in Europe (47), Australia and New Zealand (4) averages 4–5 g/d. The average starch intake (200 g/d) by our subjects was slightly higher than the U.S. average reported by Stephen et al. (46) but is within the range consumed in industrialized countries. The RS in the current study (30 g/d) was well above the 4–5 g/d consumed in Europe, Australia, or New Zealand and is higher than would be consumed in a developing country (30–40 g RS/d in ~400 g starch). Unless diets are supplemented with isolated RS sources, such as a fiber supplement, the 30 g/d or 15% of total starch appears to be an upper limit of RS consumption. Most reported research on the effects of unavailable carbohydrate on mineral retention have had relatively short feeding periods, from single meals to 4 wk. Intake of acarbose for 1 y had no adverse affect on colonic function or fecal nutrient output although SCFA were increased and pH decreased compared with pretest levels (48). Data reported here indicate that a diet high in amylose from cornstarch, containing 30 g RS, could be consumed chronically without adversely affecting mineral retention and may improve retention of some minerals.

LITERATURE CITED