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Pasta cooking time: influence on starch digestion and plasma glucose and insulin responses in healthy subjects¹⁻³

Francis RJ Bornet, Denis Cloarec, Jean-Luc Barry, Paul Colonna, Sylvie Gouilloud, Jean Delort Laval, and Jean-Paul Galmiche

ABSTRACT The influence of pasta cooking time on starch digestion and plasma glucose and insulin responses was studied in 12 healthy subjects. During 3 consecutive days, one of three pasta test meals (50 g starch) cooked for 11, 16.5, and 22 min was served to each volunteer in a random order. Hydrogen and methane breath excretion was measured after pasta ingestion; plasma responses were compared with those of an equivalent oral glucose-tolerance test. No significant differences were found between cooking times and plasma indices, orocecal transit time, or incremental hydrogen excretion (Δ peak hydrogen). With one exception, pasta meals that were completely absorbed were ingested by methane producers. Postprandial Δ peak hydrogen was significantly lower in methane than in non-methane producers ($p < 0.02$). These results point to a lack of influence of cooking time on nutritional characteristics of pasta and suggest that starch malabsorption determined by breath-hydrogen-test criteria may be underestimated in methane producers. *Am J Clin Nutr* 1990;51:421-7.

KEY WORDS Pasta, cooking time, breath-hydrogen test, breath-methane test, methane producer status, glycemic index, insulinemic index

Introduction

Starchy carbohydrates represent the major source of nutritive energy in humans. Recent investigations in man, with use of the breath-hydrogen test, indicated the existence of a malabsorption by the small bowel of most starchy foods including pasta (1, 2), which may not only modify energy food value but induce abdominal discomfort as well. Other studies showed that the digestion of durum-wheat pasta by diabetics and healthy subjects is characterized by reduced plasma glucose and insulin responses (3-5). Both sets of effects could be explained by a reduced susceptibility of pasta starch to digestion by α -amylase. Digestibility of starch in foods by α -amylase can be modified in vitro as well as in vivo by numerous factors including starch origin (6, 7), nonstarchy components such as fibers (8, 9) or glutinous protein (1, 10, 11), and food processing (12-16). The aim of this study was to evaluate the effects of pasta cooking time on plasma glucose and insulin responses and on intestinal malabsorption of starch in healthy subjects by using the breath-hydrogen and -methane test methods.

Methods

Subjects and experimental design

Twelve young healthy volunteers [six men and six women, aged 22.6 ± 2.5 y, ($\bar{x} \pm$ SD) mean body mass index 20.8 ± 2.6 kg/m²] with no history of gastrointestinal disease or diabetes gave their informed written consent to participate in a study approved by the Ethics Committee of the Hôpital Guillaume et René Laënnec.

The pasta test meals consisted of spaghetti, industrially produced (Panzani, Marseilles, France) from durum-wheat semolina and dried at a low temperature of 55 °C. The pasta (100 g dry matter) was boiled in 2 L 0.7% salted Evian (BSN Co, Evian, France) water for either 11 (T1), 16.5 (T2), or 22 min (T3) on the basis of an established reference method (17). Immediately after cooking, the water was drained for 1 min through a colander with 1-mm pores and the pasta meal was served. Each pasta test meal consisted of 50 g starch, 10 g protein, 1.6 g lipids, 275 kcal (1150 J), and a variable water content comprising 140, 180, and 220 g for the T1, T2, and T3 test meals, respectively. To ensure uniformity of water content in the three test meals, an additional drink of water of 110, 70, and 30 g accompanied the T1, T2, and T3 pasta meals, respectively. The chemical and physicochemical characteristics of pasta before and after cooking were reported by Colonna et al (18).

The order of the three pasta meals was randomly assigned to each volunteer during a 3-d consecutive test period by using a Latin-square experimental design; meals were eaten at 0900 h within 6 min after an overnight fast and immediately preceded by meticulous oral hygiene. Each evening meal preceding the morning test was standardized to contain a low level of indigestible material and consisted of fish (100 g), white rice (200

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g), white bread (80 g), a portion of Camembert cheese (30 g), and yogurt (125 g); water ingestion was permitted ad libitum.

Blood sampling and breath analysis

Baseline testing was done during the week preceding the test meals, with volunteers subjected to an oral glucose-tolerance test and a lactulose test. The glucose tolerance test (55.5 g monodehydrated D-glucose diluted in 250 mL water equivalent to 50 g starch glucose units) was performed at 0900 h after a 12-h fast. Blood samples were drawn 30 min before and every 15 min for 60 min after glucose ingestion followed by 30-min sampling during the next 2 h.

The lactulose test, consisting of 10 g lactulose syrup (Duphalac, Duphar Laboratories, Villeurbanne, France) in 100 mL water, was done at 0900 h after suitable oral hygiene (careful mouthwashing with a 1% chlorhexidine solution; Givalex, Norgan Laboratories, Paris) to reduce oropharyngeal microfloral activity (19, 20). Breath samples were collected at 15-min intervals from 30 min before lactulose ingestion until 6 h afterwards. During the test, subjects were forbidden to eat, smoke, or exercise. Hydrogen-producer status was defined as the ability of a subject to produce an increase in breath hydrogen of > 20 ppm above baseline values (nadir of the hydrogen concentration) at one or more breath collections after a standard lactulose ingestion (21, 22). Methane-producer status was defined as a mean breath-methane-sample concentration of ≥ 3 ppm above that in ambient air.

Blood samples were drawn 30 min before and every 15 min during the hour after a pasta test meal, then every 30 min for the 2 h thereafter. Samples were immediately centrifuged at $9000 \times g$ for 10 min at 4°C and frozen for later testing. Plasma glucose concentrations were assayed by using a glucose-oxidase method (Beckman Autoanalyzer II, Beckman, Fullerton, CA) with an intraassay reproducibility of 2%. Plasma insulin was tested by radioimmunoassay (Anti-insulin antibody, Novo Industri, Copenhagen) by using a charcoal separation method with an intraassay reproducibility of 6%.

The glycemic index was calculated for each pasta test meal as the ratio between the incremental areas under the 3-h glycemic response curve to a pasta meal and to the glucose tolerance test, expressed as a percent. The insulinemic index was similarly calculated from the respective insulin curves.

Breath samples were collected at 15-min intervals from 30 min before to 9 h after ingestion of a test meal. Subjects remained seated and had access to water ad libitum after the first 3-h test period. Alveolar air samples were obtained by having the subjects exhale through a mouthpiece into two bags connected by a three-way valve. When the first 500 mL of expiratory air filled one plastic bag, the end alveolar air was then collected in a second bag (1-L rubber anesthesia bag adapted with a one-way valve). The end alveolar air was then immediately transferred into 50-mL plastic syringes fitted with three-way stopcocks, and was usually analyzed within 2 h of collection (23).

The hydrogen and methane concentrations in breath samples were determined simultaneously with a MICRO LYZER DP gas chromatograph (Quintron Instrument Company, Milwaukee, WI) by using a molecular sieve column (12' Hysep Q, 60/80 mesh; Quintron Instrument Co). Dry air was used as the carrier gas at a flow rate of 40 mL/min. The chromatograph was calibrated with a hydrogen and methane reference mixture

in compressed air (Quingas 2, Quintron Instrument Co). The smallest detectable concentration of both gases was 2 ppm with a linear accuracy response range of 2–150 ppm.

During the 9-h period after the pasta test meal, an increase in hydrogen concentration of ≥ 10 ppm over baseline (nadir of the hydrogen concentration), measured upon two consecutive 15-min-interval breath samplings, was considered to represent significant starch malabsorption (24). Therefore, the orocecal transit time was defined as the time from the beginning of carbohydrate intake until the period just before the first detectable sustained increase in breath hydrogen (22, 25, 26).

Statistical analysis

Analysis of variance was used to test the effect of subjects, cooking time, and order of pasta meals. Multiple comparisons between the test-meal data were made by using the method of Newman-Keuls (27). Analysis for significance between lactulose or glucose-tolerance-test data and that of the test meals was performed by using Student's *t* test for paired data whereas comparison between methane-producer and nonmethane-producer data was made by using Student's *t* test for unpaired data. Results are expressed as means $\pm$ SEM.

Results

Responses in plasma

The mean plasma glucose responses observed 180 min after the pasta meals and glucose tolerance test are shown in Figure 1, with the mean postprandial plasma glucose variations summarized in Table 1. The mean glycemic Δ peak value occurred significantly faster ($p < 0.05$) after the T1 pasta meal (31 ± 2 min) than after the glucose tolerance test (40 ± 3 min) but not significantly faster than after the other pasta test meals (T2 and T3). After the pasta meals the mean Δ plasma glucose responses above baseline fasting concentrations were only half as high as those after the glucose tolerance test ($p < 0.001$). The mean Δ peak plasma glucose under the baseline fasting value was also significantly greater ($p < 0.001$) after the glucose tolerance test than after the pasta meals. Although there were no significant differences in the plasma glucose responses between pasta meals in the 3-h postprandial test period, plasma glucose variations and areas under the plasma glucose curves or the glycemic indexes were generally significantly different when comparing values after the pasta test meals with those after the glucose tolerance test.

The mean plasma insulin profiles observed within 180 min of the pasta meals and the glucose tolerance test are illustrated in Figure 1 and summarized in Table 2. From 15 to 120 min after the start of the tests, insulin concentrations after the glucose tolerance test and after the pasta test meals differed significantly. However, insulin responses after the three pasta meals did not differ significantly.

Breath excretion

Although all subjects were hydrogen producers, only half were methane producers as well. The mean of maximal hydrogen increment (Δ peak hydrogen) over basal breath hydrogen (nadir of the hydrogen concentration) after the lactulose test was 50.8 ± 8.4 ppm for the nonmethane producer group [group M(–)] and 38 ± 8.9 ppm for the methane producer group

FIG 1. Plasma glucose and insulin responses ($\bar{x} \pm \text{SEM}$) in 12 healthy subjects for 180 min after receiving pasta test meals cooked 11 (T1, $\square$), 16.5 (T2, $\square$), and 22 min (T3, $\blacksquare$), or after oral glucose-tolerance test ($\blacktriangle$). Each carbohydrate test contained 50 g starch or equivalent glucose units. Significance between glucose tolerance test and pasta test meals was as follows: ns, not significant; a, $p < 0.05$; b, $p < 0.02$; c, $p < 0.01$; and d, $p < 0.001$.

[group M(+)]. The difference between the mean group values was not significant.

Figure 2 shows the variations in mean breath-hydrogen concentration 9 h after ingestion of the three pasta meals. At any given time no significant differences were found in breath-hydrogen concentrations or mean Δ peak hydrogen concentrations between test meals (Table 3). The mean estimated oro-cecal transit time in subjects with starch malabsorption (7, 9, and 10 subjects after T1, T2, and T3 meals, respectively) did not differ significantly. With the exception of one meal, those 10 meals (of 36), which were apparently absorbed completely, were ingested by methane-producer subjects. Figure 3 shows the distribution of mean Δ peak breath-hydrogen concentrations after the three pasta meals for all subjects according to their methane-producer status. The mean intergroup difference, 25 ± 2 ppm for group M(-) vs 15 ± 2 ppm for group M(+), was significantly different ($p < 0.02$).

Discussion

Previous studies (10–16) emphasized the role of food processing as a factor able to modify both in vitro food-starch α -

amylase susceptibility and in vivo starch bioavailability. Digestion of food starch by pancreatic amylase can be increased by a more disorganized state of the starch molecule, obtained by heating or shearing in excess water. This maximally disorganized state is a function of swelling temperature, which depends on the type of starch used (28).

In agreement with earlier studies in diabetics (3, 5) and in healthy subjects (4), our study confirmed that ingestion of white durum-wheat flour in the form of pasta by healthy subjects led to a significantly smaller increase in plasma glucose and insulin concentrations than after an equivalent glucose solution. Mean glycemic and insulinemic Δ peaks after pasta test meals occurred more rapidly than after the glucose tolerance test. The significant difference between the glucose tolerance test and the T1 pasta meal in terms of plasma glucose peaking time may be ascribed to the relatively large time interval (15 min) between blood samplings. A shorter sampling time interval would probably have reduced the differences. Rather than consider pasta a *slow carbohydrate*, which supposes a delay in Δ peaking time and/or time to return to basal value, it may be better defined as a *low-effect carbohydrate*. Although plasma glucose concentrations decreased below fasting values after the second hour of the glucose tolerance test, this relative hypoglycemic phenomenon was not observed after the pasta meals. The more stable plasma glucose responses to pasta ingestion were a consequence of the lower insulin responses.

The lack of differences in plasmatic response and starch digestion between the three test meals are in accordance with in vitro results reported by Colonna et al (18), who showed by x-ray diffractometry or differential scanning calorimetry analysis that after cooking (T1) in boiled water, starch was yet completely gelatinized. Furthermore, in vitro starch pasta α -amylolysis performed at 37 °C (600 nkat of α -amylase) shows that starch susceptibility to amylase increases after cooking; however, overcooking had only a slight effect. This lack of effect of the cooking time on the glycemic index of spaghetti cooked 5 or 15 min was reported by Wolever et al (29) in diabetics. When α -amylase concentration is the limiting factor (activity < 600 nkat), pasta of different size and/or after different cooking times can be differentiated in vitro for its susceptibility to hydrolysis by α -amylase (18). This differentiation would be significant in vivo in subjects with low amylase secretion, such as infants, old people, or patients with deficiencies in intraluminal pancreatic enzymes.

Colonna et al (18) showed that preincubation of pasta with protease (pronase containing $< 0.1\%$ amylase activity) enhanced starch pasta amylolysis. Similar results were reported by Holm et al (10) with wheat starch, suggesting that a large fraction of the starch is encapsulated in a protein matrix. Scanning electron microscopy with use of freeze-fracturing and thin-sectioning confirmed that proteins coagulate to form a continuous network around each starch granule during pasta cooking (30), thereby providing a structural explanation for the low pasta plasma responses. The same reduced glycemic effect of starch-gluten interactions in bread was recently shown by Jenkins et al (11).

The technique of breath-hydrogen testing used here to study intestinal digestion of pasta starch, is based on the ability of colonic microflora to ferment carbohydrates unabsorbed at the end of the small intestine, with the resultant production of hydrogen. When analyzed, the raw-fiber content of pasta is

TABLE 1

Characteristics of plasma glucose response during 180 min after the start of test meals*

	OGTT	Pasta meals		
		T1 (11 min)	T2 (16.5 min)	T3 (22 min)
Fasting concentrations (mmol/L)	4.6 ± 0.1	4.4 ± 0.1 ^{aa}	4.4 ± 0.1 ^{aa}	4.4 ± 0.1 ^{aa}
Δ Peak above fasting value (mmol/L)†	2.9 ± 0.2	1.2 ± 0.1 ^{ca}	1.4 ± 0.1 ^{ca}	1.3 ± 0.2 ^{ca}
Δ Peak under fasting value (mmol/L)‡	-1.0 ± 0.1	-0.2 ± 0.1 ^{ca}	-0.2 ± 0.1 ^{ca}	-0.3 ± 0.1 ^{ca}
Peaking time (min)				
Peak above fasting value	40 ± 3	31 ± 2 ^{ba}	33 ± 3 ^{aa}	40 ± 10 ^{aa}
Peak under fasting value	130 ± 14	36 ± 17 ^{da}	69 ± 18 ^{da}	101 ± 2 ^{aa}
Area under curve (mmol · L ⁻¹ · min)				
0-15 min	6.1 ± 0.6	4.4 ± 1.1 ^{aa}	4.4 ± 1.1 ^{aa}	3.9 ± 1.1 ^{aa}
0-30 min	29.4 ± 2.8	17.2 ± 2.8 ^{ca}	17.8 ± 2.2 ^{da}	15.0 ± 2.8 ^{ca}
0-60 min	98.3 ± 8.9	40.0 ± 6.1 ^{ca}	44.9 ± 5.0 ^{ca}	37.7 ± 7.8 ^{ca}
0-90 min	138.8 ± 18.3	51.6 ± 8.3 ^{da}	55.5 ± 7.8 ^{da}	47.7 ± 11.1 ^{ca}
0-180 min	161.5 ± 26.6	71.6 ± 13.3 ^{da}	77.7 ± 12.2 ^{ca}	66.6 ± 13.3 ^{da}
Glycemic index (%)	—	59 ± 15 ^a	65 ± 15 ^a	46 ± 10 ^a

* $\bar{x} \pm \text{SEM}$. OGTT, oral glucose-tolerance test. First (or only) letter gives significance between OGTT and pasta meals, second letter gives significance between pasta meals: a, NS; b, $p < 0.05$; c, $p < 0.02$; d, $p < 0.01$; and e, $p < 0.001$.

† Difference between maximal and fasting values.

‡ Difference between minimal and fasting values.

roughly 5–6 g/100 g dry matter and principally composed of hemicellulose (31). To assess the impact of this fiber component on breath excretion, Tadesse and Eastwood (32) fed 20 g hemicellulose to humans: hydrogen excretion was only one-third that observed with lactulose. Because Flourie et al (33) recently showed that the lactulose breath hydrogen test provides a valid measurement of the mean amount of starch metabolized in the colon of healthy subjects, it seems that starch malabsorption rather than dietary fiber represents the major portion of the hydrogen excreted after pasta ingestion. The 9-h postprandial test period was insufficiently long to allow breath-hydrogen measurements to return to baseline concentrations for the quantification of starch malabsorption as described by Bond and Levitt (34); it was long enough to calculate the mouth-to-cecum transit time.

Although the fasting breath-hydrogen concentrations in our subjects were relatively high (15–20 ppm), they were in agree-

ment with those reported elsewhere (1, 2, 35). Overnight fermentation of colon-accumulated carbohydrates may account for the high initial fasting concentrations of hydrogen excretion (35, 36). Kotler et al (37) demonstrated that an evening dinner leading to carbohydrate malabsorption before the breath test can reduce fasting concentrations of breath-hydrogen. In our study those carbohydrates consumed at the evening meal included starch from white rice (50%) and white bread (50%) and lactose (7 g) from yogurt. Kolars et al (38) showed that lactose from yogurt is well absorbed, even in lactase-deficient subjects. Nevertheless, if a fraction of bread starch is incompletely absorbed (2, 11), such a quantity cannot account alone for the high fasting concentrations of hydrogen excretion 12 h after the start of a meal (11). Fermentation of mucins and glycoproteins have also been implicated in high fasting concentrations of breath hydrogen (39).

Immediately after pasta ingestion an initial increase in mean

TABLE 2

Characteristics of plasma insulin response during 180 min after the start of test meals*

	OGTT	Pasta meals		
		T1 (11 min)	T2 (16.5 min)	T3 (22 min)
Fasting concentration (pmol/L)	83.2 ± 4.3	74.6 ± 3.6 ^{aa}	73.9 ± 3.6 ^{aa}	81.8 ± 3.6 ^{aa}
Δ Peak above fasting value (pmol/L)†	482.9 ± 51.7	109.8 ± 12.2 ^{da}	108.3 ± 20.1 ^{da}	124.1 ± 23.7 ^{da}
Peaking time: peak above fasting value (min)	54 ± 4	36 ± 4 ^{ca}	35 ± 5 ^{ca}	53 ± 12 ^{ca}
Area under curve (nmol · L ⁻¹ · min)				
0-15 min	0.9 ± 0.1	0.4 ± 0.1 ^{ba}	0.6 ± 0.1 ^{aa}	0.4 ± 0.1 ^{ba}
0-30 min	4.2 ± 0.4	1.6 ± 0.3 ^{da}	1.8 ± 0.3 ^{da}	1.6 ± 0.4 ^{da}
0-60 min	16.7 ± 1.5	3.9 ± 0.6 ^{da}	4.2 ± 0.9 ^{da}	4.3 ± 1.1 ^{da}
0-90 min	27.8 ± 3.4	5.5 ± 0.8 ^{da}	6.1 ± 1.4 ^{da}	6.2 ± 1.5 ^{da}
0-180 min	40.8 ± 7.1	8.5 ± 1.5 ^{ca}	10.7 ± 2.8 ^{da}	10.0 ± 2.4 ^{da}
Glycemic index (%)	—	26 ± 5 ^a	28 ± 6 ^a	26 ± 6 ^a

* $\bar{x} \pm \text{SEM}$. First (or only) letter gives significance between OGTT and pasta meals; second letter gives significance between pasta meals: a, NS; b, $p < 0.05$; c, $p < 0.02$; d, $p < 0.01$; and e, $p < 0.001$.

† Difference between minimal and fasting values.

FIG 2. Breath-hydrogen excretion ($\bar{x} \pm \text{SEM}$) in 12 healthy subjects after receiving pasta test meals cooked 11 (T1, $\square$), 16.5 (T2, $\square$), and 22 min (T3, $\blacksquare$). No significant differences were observed between the test meals at any time.

breath-hydrogen concentration was noted, followed by a gradual decrease to basal concentrations. Various hypotheses have been proposed to explain the early increase in breath hydrogen (40, 41). Because buccal carbohydrate fermentation contributes to some degree, oral hygiene has been proposed to eliminate this phenomenon (19). Despite the meticulous oral hygiene practiced in our trial, its effect seemed insufficient to to-

FIG 3. Maximal breath-hydrogen increments after pasta test meals for six nonmethane producers (M-) and six methane producers (M+). Each triangle represents the mean value of the three test meals for a subject. Horizontal bars indicate mean value for each group. The difference between the mean group values was significant ($p < 0.02$).

tally eliminate the initial increase in hydrogen (42). It has also been hypothesized that soon after food ingestion, hydrogen production may be stimulated by the passage into the cecum of either ileal secretions or carbohydrates retained in the terminal ileum from a previous meal (40).

On the basis of the functional criterion defining starch malabsorption, 26 of 36 pasta meals were incompletely digested in the small bowel of the test subjects. Levitt et al (2) showed recently that 50-g starch doses in the form of various starchy foods (oats, potatoes, corn) gave rise to approximately one-half the hydrogen excretion observed with 100-g doses. These data suggest that at least in healthy humans, the limiting factor for intestinal absorption of starch is the specific resistance of a given food to α -amylolysis rather than to a deficit in enzyme availability. When comparing our data for pasta with their results, we estimate a starch pasta malabsorption of $< 4\%$, whatever the cooking time. This percentage is considerably less than the 10–20% estimated by Anderson et al (1), who used 100 g starch in the form of macaroni boiled for 7 min. It has been suggested that it is the protein moiety of durum-wheat flour that interferes with starch digestion (1, 10, 11, 18).

The criteria used to define a subject as a methane producer has varied. Initially, Bond et al (43) proposed that only those subjects with breath methane concentrations > 1 ppm above

TABLE 3
Breath-hydrogen excretion after lactulose test and pasta test meals*

	Lactulose	Pasta meals		
		T1 (11 min)	T2 (16.5 min)	T3 (22 min)
Δ Breath-hydrogen concentration (ppm)†	45 ± 4	20 ± 1^{aa}	19 ± 1^{aa}	22 ± 1^{aa}
Beginning of hydrogen excretion (min)	85 ± 13	274 ± 27^{ba} [7]	238 ± 88^{ba} [9]	278 ± 49^{ba} [10]

* $\bar{x} \pm \text{SEM}$. $n = 12$ except where noted differently in brackets. First letter gives significance between lactulose and pasta meals; second letter gives significance between pasta meals: a, NS, and b, $p < 0.001$.

† Difference between the maximal increment of hydrogen concentration and the nadir of hydrogen concentration.

atmospheric methane be arbitrarily designated as methane producers. However, a single breath sampling may fail to detect an average of 18% of the methane producers in a given population (44). More recently, McKay et al (45) demonstrated that all healthy subjects may produce methane, though production of the gas appears in breath only after reaching a certain threshold. These investigators defined a methane producer as a subject emitting ≥ 2 ppm above room air concentration, on the basis of the sensitivity and reproducibility of the method used. In our study the smallest detectable methane concentration was 2 ppm; thus, our methane producers were defined as subjects producing mean methane concentrations of ≥ 3 ppm above those in ambient air after two breath samples.

Our results demonstrated a significant difference in breath-hydrogen concentration between healthy methane and non-methane producers after pasta test meals, with a lower mean breath-hydrogen concentration peak in the methane producers. With one exception, those subjects who did not show evidence for starch malabsorption were all methane producers as well.

Hydrogen and methane in human breath derive entirely from bacterial fermentation in the intestinal lumen; neither hydrogen nor methane are used by cells of human organisms. In vivo methane production does not seem to be influenced by acute ingestion of carbohydrates such as starch (41), beans, or onions (46). However, dietary pectin (47) or xylane (48) can increase baseline concentrations of breath methane. Only large lactulose loads (≥ 20 g) can increase methane production (49). Methane production has been correlated with basal methane concentrations. Björneklett et al (50) found that, in healthy subjects, methane producers who excreted > 10 ppm methane had significantly lower fasting breath hydrogen and breath-hydrogen excretion after ingestion of 33 g lactulose than did methane producers who excreted < 10 ppm. These results and our own suggest that hydrogen production might be related to methane-producer status. Therefore, we may well have underestimated the number of pasta meals that have been incompletely absorbed by methane producers. In such a subpopulation the criteria heretofore used to assess starch malabsorption when using the breath-hydrogen method may not be adequate. If revised criteria are not established to gauge malabsorption of starchy foods in methane producers, it may be necessary to either increase the amount of starch tested, which must then be considered as an extraphysiologic meal, or to select only non-methane producers as subjects. $\S$

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