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Short Communication

Homemade Gluten-Free Pasta Is as Well or Better Digested Than Gluten-Containing Pasta

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The life and well-being of gluten-intolerant individuals (patients with celiac disease), estimated at more than 2 million in the European Union (1–3), depend entirely on strict compliance with a gluten-free diet. Gluten-containing foods constitute the staple diet in many countries. For instance, in Italy, pasta in one form or another is served at practically all meals. Pasta is also regularly consumed in most Mediterranean countries, and with the Mediterranean diet currently in fashion, in most of Europe and the United States. The weekly consumption of pasta is also spreading in North Africa.

Consequently, gluten-intolerant individuals have difficulty in adjusting to a pasta-free diet. This restriction is a serious problem for many adults with celiac disease, much more so than refraining from eating bread or biscuits (4). Pasta and bread are the major causes of noncompliance with a gluten-free diet (5). Although the quality of commercially available gluten-free pasta has improved, it is five times more expensive than normal pasta, at least in Italy, and there is some aftertaste and cooking problems.

The Italian National Health Service (NHS) pays for an average of 12 kg/mo of gluten-free products for each patient with celiac disease aged 12 years or more. From 40% to 60% of the cost is for gluten-free pasta, amounting to an annual expenditure by the NHS estimated at between 10 and 15 million European Currency Units [ECU]/year (6).

Homemade gluten-free pasta has not been a success, because the ingredients do not mix easily, and the pasta disintegrates. Gluten-free flour is commercially available, but it has the same drawbacks and costs the same as commercial gluten-free pasta.

Gluten-free products are licensed purely on the basis of absence of gluten. No studies have been performed on the nutritional value or digestibility of gluten-free products. We devised a recipe for homemade gluten-free pasta and compared gastric emptying, residual hydrogen production, and glycemic response after a meal of gluten-free versus ordinary gluten-containing pasta. We also evaluated its palatability in 20 healthy volunteers.

SUBJECTS AND METHODS

Twenty healthy medical students less than 30 years of age, body mass index less than 25 kg/m^2, gave their signed informed consent to the study. The Ethics Committee of the School of Medicine (University of Naples "Federico II") approved the study design. After a 15-hour fast, the 20 students ate 100 g (dry weight) of home-made gluten-free tagliatelle or ordinary gluten-containing tagliatelle made with the best Italian durum wheat, at an interval of 1 week, in a blind random fashion (random numbers allocation).

With an intravenous catheter inserted into an antecubital vein, blood samples were collected before and 1, 2, 3, and 4 hours after each meal. The glucose contained in each sample was measured by a standard enzymatic-colorimetric method (7), and plasma insulin was assayed by radioimmunoassay (8).

Antral volume was measured by a ultrasound scan using a digital ATL HDI echograph (HDI 3000; HDL ultrasound, U.S.A.) with a convex-array scan of 3.5 MHz. Ultrasonographic measurements were limited to the final section of the stomach (antrum and pylorus), which is constantly visible, and where the volume can be measured in a relatively simple way. Scanning was done with the subject in a standing position so that air rose toward the bottom of the stomach. The measurements were obtained at fasting and every 30 minutes after the end of the meal until the volume of the antrum returned to fasting values. The antral volume was calculated using three sagittal scans at the level that measures the longitudinal and anteroposterior diameters. The first scan was performed on the region of the angulus (transitional region between the body of the stomach and the antrum pylorus); the second was run at the level of the mesenteric superior vein, which is easily detectable; and the third was run at the level of the pyloric sphincter where the depth of the muscle wall is visible. Finally, using a transverse scan, we measured the antral length from the angulus region to the pylorus.

The volume of the antrum was calculated using the formula: $0.065 \times h \times (2ab+2ef+4cd+cb+ad+ed+cf)$ of Bolondi et al. (9),

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TABLE 1. *Nutritional values/100 g dry product*

	Gluten containing	Gluten free
KCal	366	347
Protein (%)	13.8 g	10.2 g
Fat (%)	5.0 g	5 g
Carbohydrate (%)	69.5 g	71 g

where h is the antral length; a, c and e, are the longitudinal diameters; and b, d, and f are the anteroposterior diameters. This method was validated by Bolondi et al. versus the gold standard scintigraphic method (9). A quality check on the reproducibility of measures was run on 10 volunteers, who were evaluated twice after the same meal: the correlation coefficients between first and second estimation ranged from 0.82 to 0.98. The ultrasound scan parameters used in this study showed the best values.

Hydrogen production in the expired air was detected at fasting and at 2, 4, and 6 hours and hourly up to 13 hours. Alveolar air samples were collected after a normal inspiration held for 5 seconds before exhalation. When the first 500-mL expiratory air filled one plastic bag, the end alveolar air was collected in a second bag. The end alveolar air was analyzed within 24 hours (10,11). The hydrogen and CH_4 in the breath was measured simultaneously using the gas chromatographic method (Microlyzer SC; Quintron, Milwaukee, WI, U.S.A.; a chromatograph with two columns separating hydrogen and methane in one and carbon dioxide in the other). Results are expressed as parts per million (1 ppm = approximately 0.61 μmol/L for H_2 and 0.076 μmol/L for CH_4). For both gases, the smallest detectable concentration was 2 ppm with a linear accuracy response range of 2 to 100 ppm. In subjects who produce CH_4, H_2 formed by fermentation is in part converted into CH_4 according to the equation $4\ H_2 + CO_2 = CH_4 + 2\ H_2O$ (12). On the basis of this equation and of density of expired air (approximately 1.2 g/L at 1 atm, 25°C), we transformed the amount of CH_4 produced by our subjects in H_2 with the formula: CH_4 (μmol/l) = $0.076 \times CH_4$ (ppm); and H_2 (μmol/L) = $0.61 \times H_2$ (ppm). Total breath H_2 (ppm) for each subjects was obtained summing [$(4 \times CH_4$ (μmmol/L) + H_2 (μmol/L)]/0.6 at each time point. A baseline breath test was run with lactulose in a standard dose of 5 g.

Gluten-Free Pasta

The gluten free pasta was prepared at home: 350 g of rice flour, 150 g of maize starch, 150 g of potato starch, and eight whole eggs (420 g) yielded 1 kg of fresh pasta. The mix was manually kneaded thoroughly for 5 minutes. Repeated trials showed that the pasta was easier to handle when Asian "glutinous" rice flour was used, and it was easier to cut tagliatelle or other pasta shapes. Glutinous rice is produced in Asian countries. It is defined as rice containing rice glue (i.e. prolamins) and is traditionally used in Asia to make noodles and cookies. The sheet of pastry was cut with an inexpensive pasta-cutting device, but a knife serves just as well. The kilogram of fresh pasta, left to dry overnight at room temperature, yielded 750 g of dry product. Stored at 4°C, the pasta remained stable for at least 2 months. The commercial gluten-containing pasta was made from 670 g of hard (durum) wheat flour industrially mixed with 330 g of whole eggs.

Both gluten-free and gluten-containing pasta were cooked in salted boiling water, and both remained al dente. When the pasta was cooked, the weights of both were identical (i.e., they absorbed equivalent amounts of water).

The pasta was seasoned with 100 g of tomato sauce (92 g processed tomato, 8 g olive oil, and salt). The composition and nutritional value of the two meals is reported in Table 1.

Statistical Analysis

Measured data are expressed as mean ± SE. Differences between the two test meals, measured before and after the test meals were evaluated by Student's paired *t*-test. The Komogorov–Smirnov test showed a normal distribution of the variables. Subjective data were compared by a Wilcoxon test. The geometric means of plasma glucose, plasma insulin, and alveolar hydrogen areas were used. Gastric emptying time was the time required for antral volume to return to fasting value. It was calculated from the regression equation for antral volume against time (i.e., the time elapsed from the maximal value to return to baseline).The level of statistical significance was set at $P = 0.05$ (two tailed).

RESULTS

Palatability

Volunteers were blind to the type of pasta served. All subjects finished their meals. After the meal, subjects completed a form on which they were requested to give a score from 0 to 4 to each of the following items: taste and texture of the pasta and their sense of fullness and satiety. There was no difference between the gluten-containing and the gluten-free pasta meals in taste (Table 2). The gluten-free pasta was perceived to be better in texture than the gluten-containing pasta, and the sense of fullness and postprandial satiety were less with the gluten-free pasta. No negative or extreme opinion was expressed for either meal.

Glycemic Response

Fasting plasma glucose (96 ± 3 mg/dL versus 93 ± 2 mg/dL) and insulin concentrations (6.17 ± 0.36 mg/dL versus 6.43 ± 0.41 mU/mL) were similar before the two test meals. The gluten-free pasta elicited a significantly higher postprandial plasma glucose response at 60 and 120 minutes ($P < 0.05$); the response decreased at 180 and 240 minutes (Fig. 1A), so that at 240 minutes the values were similar for the two meals (21,920 ± 639

TABLE 2. *Self-perceived quality of the products tested: Median values from a score 0 to 4**

	With gluten	Without gluten	*P*†
Taste	3	3	0.57
Texture	3	2	0.0001
Fullness	3	2	0.0076
Satiety	3	2	0.018

* Median values overlap with mode values.
† Wilcoxon matched pairs signed rank test.

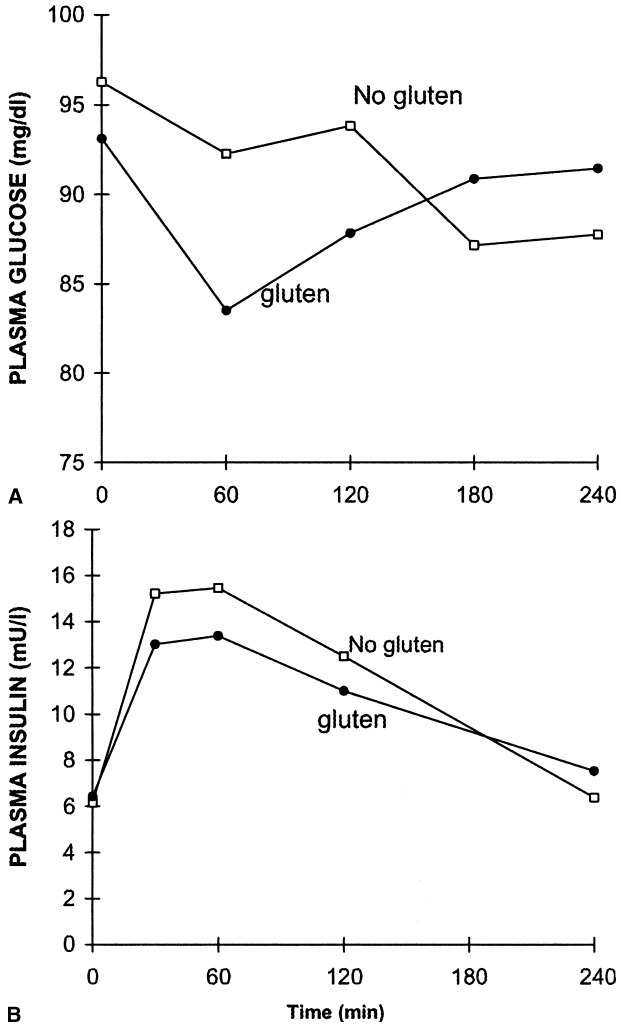

FIG. 1. Postprandial plasma glucose (**A**) and insulin (**B**) responses to the gluten-free pasta meal o and gluten-containing pasta meal l (*$P < 0.05$).

mg/dL versus 21,275 ± 469 mg/dL; $P = 0.18$; incremental area, 840 ± 240 mg/dL versus 1,191 ± 269 mg/dL; $P = 0.83$). The postprandial plasma insulin response was similar after the two meals (Fig. 1B), but the gluten-free pasta caused a significantly greater increase of plasma insulin area up to 240 minutes (2,967 ± 219 mU/mL versus 2,664 ± 192 mU/mL; $P < 0.05$; incremental area, 1510 ± 215 mU/mL versus 1,122 ± 156 mU/mL; $P < 0.02$).

Gastric Distension and Emptying

Figure 2A shows the antral dimension mean profiles after the two meals. Maximum antral volume, reached 1 hour after the meal, was greater after the gluten-containing meal and remained greater up to total emptying. Gastric emptying (return to fasting values) occurred 43 minutes earlier after consumption of gluten-free pasta than after gluten-containing pasta ($P < 0.00003$; Fig. 2B).

Hydrogen Production

Hydrogen production was minimal after both meals, but 199 ppm/hr hydrogen was produced after consumption of gluten-containing pasta; this valued peaked at 11 hours, corresponding to approximately 17.7 g of undigested carbohydrate (5 g lactulose produced 56 ppm hydrogen), which is significantly more than after consumption of gluten-free pasta (166 ppm/hr, corresponding to 14.8 g of undigested carbohydrate).

DISCUSSION

Gluten-free pasta was as palatable as gluten-containing pasta. No significant differences in taste were noted compared with a top Italian brand of durum wheat pasta. After ingestion of a full plate of pasta, volunteers blind to gluten content thought that gluten-free pasta was lighter and gave a lesser sense of fullness and satiety.

The homemade gluten-free pasta cost approximately 1.9 ECU/kg, which compares favorably with the cost of gluten-containing pasta at 1.8 ECU/kg. Gluten-free pasta

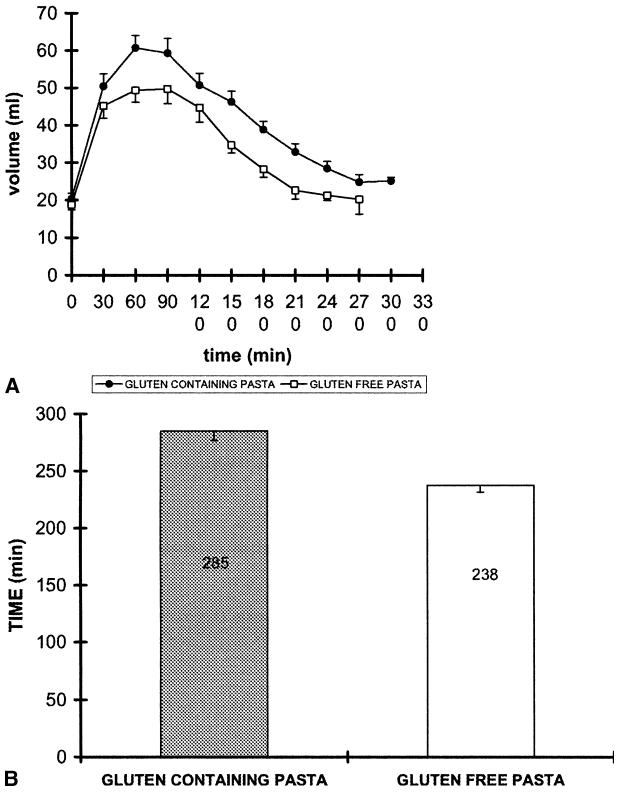

FIG. 2. Gastric antrum volume (**A**) and gastric emptying time (**B**) before and after the gluten-free pasta meal o and gluten-containing pasta meal l (*$P < 0.05$; **$P < 0.001$; ***$P < 0.0001$).

is easy and quick to prepare (approximately 35–45 minutes to make a kilogram of pasta), and it can be made once every 2 months and stored. The method is within everyone's ability, and no special equipment is required.

The gluten-free pasta induced an earlier plasma glucose response in the first 2 hours after the meal, but had no peculiar effect on the overall postprandial plasma glucose response. The earlier increase of plasma glucose response induced by the gluten-free pasta was associated with a higher postprandial plasma insulin response, expressed as absolute area under the 240-minute curve.

Maximum gastric distension and gastric emptying times were smaller and shorter with gluten-free pasta. The difference in total gastric emptying time between the two pastas was 43 minutes on average. The earlier glycemic response after the gluten-free pasta meal is probably mediated by a shorter gastric emptying time related to the absence of the glutinous component of the meal.

The amount of hydrogen production in the expired air was approximately 20% less with gluten-free than with ordinary pasta. This effect cannot be attributed to the amount of carbohydrate, because it was the same in the two meals, but rather to the different structure of gluten-free homemade pasta with respect to gluten-containing pasta. Indeed, the type of starch contained in carbohydrate-rich foods in addition to food preparation technology can modify the carbohydrate digestibility and absorption of nutrients in human intestine (14).

In conclusion, gluten-free pasta is palatable, inexpensive, and nutritionally as valid or better than gluten-containing pasta. With gluten-free pasta, the sense of fullness is reduced, and the amount of colonic fermentation decreased. The sense of satiety (gastric distension and later glycemic response) observed for the traditional pasta could be considered an advantage, but the reduced sense of fullness, an earlier glycemic response, and a minor amount of undigested carbohydrate indicate better nutritional efficiency of the alternative product.

The daily life of several million patients with celiac disease worldwide is governed by the need to avoid gluten: Pasta is a temptation for most, but for many pasta was the daily meal before the diagnosis. Avoidance of this food emphasizes the patient's disease status. Gluten-free industrial products are expensive and are not universally available. In many countries (e.g., Central and South America and North Africa) they are beyond the reach of ordinary people. In addition, commercial gluten-free products are not to everyone's liking. Celiac disease is a public health problem in Northern African countries, and industrial gluten-free foods are beyond the reach of most. Recently, gluten-containing pasta (imported or locally produced) has gained such popularity that it is consumed 1 to 3 times/week in most cities, adding the burden of imported food habits to the traditional foods. Persons with celiac disease have to avoid the local gluten-containing staple and also "western" pasta. An appropriate use of locally produced ingredients may provide unexpected solutions, as is well shown by results in this study.

Despite the widespread consumption of gluten-free products in the Western world, no data are available on their digestibility. The addition of gluing components, such as guar powder, probably delays gastric emptying significantly and increases the amount of undigested starch.

The homemade pasta described here overcomes these limitations. It appears to be good, not only for gluten-intolerant individuals, but also for healthy people.

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