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ORIGINAL ARTICLE

Effect of baking process on postprandial metabolic consequences: randomized trials in normal and type 2 diabetic subjects

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Objective: To determine the impact of the form, fibre content, baking and processing on the glycaemic, insulinaemic and lipidaemic responses of different French breads.
Design and Subjects: *First study*: Nine healthy subjects were randomized to consume in a crossover design one of six kinds of French bread (each containing 50 g available carbohydrate): classic baguette, traditional baguette, loaf of wholemeal bread (WM-B), loaf of bread fermented with yeast or with leaven, a sandwich and a glucose challenge as reference.
Results: The glycaemic index (GI) values ranged from 57 ± 9% (mean ± s.e.m.), for the traditional baguette, to 85 ± 27% for the WM-B. No significant difference was found among the different tested bread. The insulinaemic index (II), however, of the traditional baguette and of the bread fermented with leaven were lower than the other breads (analysis of variance: $P<0.01$). Postprandial plasma triglycerides showed similar profiles. The traditional baguette tended to decrease postprandial free fatty acids compared to levels after the classic baguette.
Second study, we aimed to re-evaluate the values of the GI of the classic and traditional French baguettes (TB) in another population (type 2 diabetics, $n=9$).
Results: The GI of the traditional baguette was lower than that of the classic baguette ($n=8$, venous blood: 70 ± 4 vs 75 ± 4, $P=0.002$; capillary blood: 69 ± 5 vs 83 ± 6, $P=0.028$, respectively).
Conclusions: Some varieties of French bread (the TB) have lower II, in healthy subjects, and lower GI, in type 2 diabetic subjects, than that of the other varieties. These results might be due to bread processing difference rather than fibre content.
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Introduction

Increasing postprandial plasma glucose and insulin levels are assumed to increase severity of diabetes and to be independent predictors of risk for atherosclerotic diseases and adiposity. Lowering postprandial plasma glucose and insulin responses are relevant in preventing and managing diabetes mellitus (Bonora and Muggeo, 2001; Liu *et al*., 2000a, b).

Current dietary recommendations promote the consumption of cereal products (USD, 2000; Mann *et al*., 2004). However, some studies suggest that refining of cereals may increase the glycaemic response to the food and in turn increase the risk of diabetes (Liu *et al*., 2000a, b). Habitual consumption of carbohydrate (CHO) foods induces a rise in postprandial blood glucose concentrations (high-glycaemic index (GI) foods), could initiate a sequence of metabolic events that stimulate hunger (Holt *et al*., 1992; Pawlak *et al*., 2004), promote fat deposition and deteriorate β-cell function. Additionally, other studies suggested that benefits from

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cereal products may relate only to whole grains and cereal fibres (Liu *et al*., 2003).

Bread is an essential cereal component of the Western diet, and is considered an indispensable element in the food of all the members of the family (children, adults as well as aged persons). Baking breads differs from one country to another. Even in the same country, baking bread has become an art, which is in continuous development and results in various methods of baking and different kinds of bread.

In the literature, there is no clear information on the postprandial metabolic responses to the ingestion of different kinds of French breads. According to a single study in the 1980s to validate the concept of the GI in mixed meals, the GI of the (so-called) French baguette has been cited to have a very high GI comparable to that of glucose (Bornet *et al*., 1987). Moreover, the effect of the other kinds of French bread on postprandial plasma glucose levels as well their GI have not yet been evaluated. GI data of other American and European white breads are inevitably applied to all other French breads. Because bread makes a large contribution to the glycaemic load of a Western diet, it is reasonable to question whether the various kinds of bread can modify differently postprandial metabolism in health and disease. Therefore, in the present study, we aimed to determine the impact of the form, fibre content, fermentation procedures, baking and processing of different French breads on postprandial plasma glucose levels and the GI value.

Moreover, reducing the GI of a starchy food may reduce insulin demand (Liljeberg and Bjorck, 1996) and might induce less suppression of free fatty acids (FFA) in the post-absorptive state (Kiens and Richter, 1996), increasing hence satiety and decreasing food intake at the time of the next meal. Therefore, plasma insulin and lipid responses were also evaluated after a challenge of the different kinds of French breads. Emphasis was placed to determine the precise available CHO content of different experimental breads.

Materials and methods

Test meals

Six kinds of French bread were tested: (1) classic French baguette (CB), (2) traditional French baguette (TB), (3) loaf of wholemeal French bread (high-fibre), (4) loaf of French bread fermented with yeast (Yeast-B), (5) loaf of French bread fermented with leaven (Leaven-B) and (6) CB as a sandwich (to determine the effect of a light French mixed meal using the classic baguette) and a reference glucose challenge.

Preparations and recipes

*The classic French baguette***.** The breads were prepared from 2 kg of wheat flour (type 65: advanced milling process) containing 40 mg ascorbic acid, 1260 g water (8°C), 50 g yeast and 36 g NaCl. The ingredients were mixed (with the exclusion of NaCl) and kneaded in an intensive manner: 4 min at slow speed followed by 15 min at a rapid speed. The salt was added at the end of kneading to obtain white crumb. The dough was then divided into pieces of 250 g and shaped in the form of baguette; 10 min was left before slowing down the fermentation at 7°C for 780 min. Baking was performed at 240°C for 22 min in a convection oven.

The resulting bread is characterized by white crumb with regular soft alveoli and slightly soft thin crust.

*The traditional French baguette***.** The breads were prepared from 2 kg of wheat flour (type 65 special for TB: means advanced milling of wheat), but *without any additives* (very pure flour without ascorbic acid), 1260 g water, 20 g yeast (smaller amount than that used in the classic baguette) and 36 g NaCl. The ingredients were mixed and kneaded *in a traditional procedure*: 10 min at slow speed followed by only 4 min at a rapid speed. The salt was added 1–2 min from the beginning of kneading to obtain light brownish (off-white) crumb. The dough then was fermented in oven for 60 min at 30°C. The obtained dough was somewhat sticky; this suppleness facilitates the expansion in the beginning of baking. Some flour was spread on this dough to reduce the stickiness, and then it was divided into pieces of 250 g and shaped in the form of baguettes. Ten minutes was left before blocking (slowing down) the fermentation at 8°C for 900 min. Baking was performed at 240°C for 22 min in a convection oven.

The resulting bread was characterized by off-white crumb with slightly rigid irregular alveoli with thick walls and a crusty crust.

*Wholemeal bread***.** The breads were prepared from 2 kg of wheat flour (type 150: whole-grain wheat flour) containing 40 mg ascorbic acid, 1300 g water (14°C), 50 g yeast and 36 g NaCl. The ingredients were mixed and kneaded in an intensive manner: 4 min at slow speed followed by 15 min at a rapid speed. The salt was added at the beginning of kneading to obtain light brownish crumb (as the traditional baguette). The dough was then fermented in a container for 30 min at 27°C, consequently divided into pieces of 500 g and shaped in the form of loaves. Twenty minutes was left before blocking the fermentation at 7°C for 780 min. Baking was performed at 235°C for 35 min in a convection oven.

*Bread fermented with yeast***.** The breads were prepared from 2 kg of wheat flour (type 65) containing 40 mg ascorbic acid, 1260 g water (8°C), 50 g yeast and 36 g NaCl. The ingredients were mixed and kneaded in an intensive manner: 4 min at slow speed followed by 15 min at a rapid speed. The salt was added at the end of kneading to obtain a white crumb (as the classic baguette). The dough was then divided into pieces of 500 g and shaped in loaves. Ten minutes were left before blocking the fermentation at 7°C for 780 min. Baking was performed at 235°C for 35 min in a convection oven.

Bread fermented with leaven. The breads were prepared from 2 kg of wheat flour (type 65) containing 40 mg ascorbic acid, 1240 g water (28°C), 20 g yeast, 200 g leaven and 36 g NaCl. The leaven was prepared first from 1 g starter (flora pan L/62) mixed with 1 kg of wheat flour (type 65) and 1 kg water. The ingredients were mixed and kneaded in an intensive manner: 4 min at slow speed followed by 15 min at a rapid speed. The dough then was fermented in a container for 30 min at 27°C. The dough was then divided into pieces of 500 g and shaped in the form of loaves. Twenty minutes was left before blocking the fermentation at 6°C for 780 min. Baking was performed at 235°C for 35 min in a convection oven.

The sandwich (Sand) was composed of a portion of Classic baguette with 10 g butter and two slices of Ham.

Each of the six test foods and the reference test (glucose solution) were consumed as portions providing 50 g available CHO. The estimation of the portion size containing 50 g available CHO was based on values obtained after analysing fresh samples of bread used in the experiment (Table 1). The portion sizes given to the subjects are cited in Table 1. All kinds of bread were analysed to determine macronutrients, total fibre, resistant starch content as well as water content. Total starch content and resistant starch were determined as described previously (Faisant *et al*., 1995; Champ *et al*., 1999).

All the quantities of bread used in the experiment were prepared from the same sample of flour, by the same group of bakers and within the same experimental procedures. All tested breads were prepared in the morning of the study.

Subjects and study design

First study: in healthy subjects

Nine men were selected from volunteers in good health as ascertained from a clinical examination by a physician. Subjects were screened for body weight, body mass index (BMI), plasma glucose and lipids before being selected. Inclusion criteria included: male subject, age between 20 and 50 years, BMI: $\leqslant 25\ kg/m^2$, plasma glucose $\leqslant 6.1$ mmol/l and triglycerides $\leqslant 1.69$ mmol/l. Subjects with renal, hepatic and thyroid problems, as determined by past history, physical examination, blood cell count and standard biochemical blood profile, were excluded. Another exclusion criteria was the use of medications that might affect glucose, insulin or lipid metabolism. None of the subjects had gastrointestinal neuropathy. The Ethical Committee of Hotel-Dieu Hospital approved the experimental protocol. The purpose, nature and potential risks of the study were explained and a written informed consent was obtained from each subject.

After being screened for eligibility, nine young male adults were enrolled in the study. Their clinical and biological characteristics are given in Table 2. Each subject was studied on seven separate occasions in the morning after a 10–12 h overnight fast. The subjects were instructed by a dietitian to consume a standard light low-fibre meal in the evening before the GI testing owing to the second meal effect (Robertson *et al*., 2003; Weickert *et al*., 2005; Granfeldt

Table 2 Characteristics of subjects in the two experiments

	Healthy subjects	*T2D subjects*[a]
Number of subjects	9 men	9 men
Age (years)	26.1±1.6	46.0±3.0
Body weight (kg)	72.9±1.0	86.0±3.0
Fasting plasma glucose (mmol/l)	4.4±1.0	8.8±1.5
Total cholesterol (mmol/l)	4.1±0.2	5.7±0.2
Triglycerides (mmol/l)	0.7±0.1	1.6±0.2

Values are means±s.e.m.
[a]T2D subjects: subjects with type 2 diabetes.

Table 1 Nutritional composition (g/100 g) of the final baked tested breads and the portion size of each test breakfast

	Classic baguette	*Traditional baguette*	*Loaf fermented with yeast*	*Loaf fermented with leaven*	*Wholemeal loaf*	*Sandwich*[b]
Water	25.5	26.9	36.6	33.9	34.0	25.5
Lipids	2.5	1.1	1.0	1.3	1.3	13.9
Proteins	9.2	8.8	7.9	8.0	8.4	29
Available carbohydrates	59.9	60.9	51.9	54.7	50.7	60.1
Fibre	2.9	2.3	2.6	2.1	5.6	2.9
RS	1.10	0.43	1.20	1.20	0	1.10
Energy (kcal)	299	288	248	262	248	481.5
Energy (kJ)	1269	1224	1054	1112	1052	2043
Portion size[a] *(g)*						
Bread	83.5	82	96.3	91.5	98.6	83.3
Ham (two slices)						25
Butter						10

Abbreviation: RS, resistant starch.
[a]The portion size of each test was adjusted to contain 50 g available CHO.
[b]Classic baguette + ham + 10 g butter.

et al., 2006). Only water, tea or coffee were allowed in the evening before the study. The subjects were not allowed to drink alcohol during 2 days before the tests. Smoking was forbidden during the evening before the study and at the test morning. In the morning of the study, the subjects were randomized to consume 50 g available CHO in the form of one of the six kinds of French bread or of the glucose challenge. Two hundred millilitres water was served with each test with bread. The solid mass of tested breads has been cited in Table 1. The tests were performed approximately 1 week apart and started at the same time in the morning. The reference test had been made once, and not twice as recently recommended (Brouns *et al*., 2005), owing to the high number of tests needed from each subject.

On each test day, upon arrival at the laboratory, an indwelling catheter was inserted into a vein in the cubital fossa for blood sampling. After a fasting blood sample, subjects were required to consume the entire challenge of glucose or bread (equi-CHO amount: 50 g available CHO) in 10 min. Further blood samples were taken at 15, 30, 60, 90 and 120 min after starting to eat. Blood samples were centrifuged immediately and plasma was separated. Plasma glucose was assayed at once and plasma then frozen at $-20^{\circ}C$ for ultimate measurements of plasma insulin and lipids. Venous, and not capillary, samples were used because a sufficient amount of blood was needed to evaluate also changes in plasma insulin and lipid levels. Current recommendations are that capillary blood sampling is preferred for determining the GI (Wolever *et al*., 2003; Brouns *et al*., 2005), but that it is acceptable to use venous blood sampling (FAO/WHO, 1998).

Second study: in type 2 diabetic subjects

As in the present study, the traditional baguette induced the lowest postprandial insulin responses and consequently the lowest insulinaemic index (II) in healthy subjects (see 'Results' and 'Discussion' Sections); we aimed to evaluate and to verify the values of the GI of the traditional baguette, compared to the commonly consumed bread in France, the classic baguette, in another population with impaired glucose metabolism (subjects with type 2 diabetes (T2D)). In this population, plasma glucose responses to CHO diets are more pronounced.

Nine T2D patients were selected on the basis of having fasting plasma glucose more than 6.9 mmol/l, but without abnormal triglyceride levels ($\leqslant$1.69 mmol/l). Subjects with renal, hepatic and thyroid problems, as determined by past history, physical examination, blood cell count and standard biochemical blood profile, were excluded. Subjects' ongoing therapy was: diet alone (one subject) and/or oral hypoglycaemic agents (sulphonylurea, metformin and/or thiazolidinediones). All subjects kept the same therapy during the experimental period. On the study day, patients took their respective hypoglycaemic treatment at the end of the test and not before.

Subjects were randomized to consume either 50 g glucose or the equivalent in available CHO as classic or traditional baguettes with 200 ml water. The subjects followed the same protocol as in healthy subjects. The tests were performed approximately 1 week apart and started at the same time in the morning. Blood samples were taken during 3 h for measuring plasma glucose concentrations at 0, 15, 30, 60, 90, 120 and 180 min. Both venous and finger-prick capillary blood samples were collected to measure blood glucose levels (to compare the two blood-sampling methods).

The Ethical Committee of Hotel-Dieu Hospital approved the experimental protocol. The purpose, nature and potential risks of the study were explained and a written informed consent was obtained from each subject.

Analytical methods

Plasma glucose was measured by the glucose oxidase method with a glucose analyzer (Beckman, Fullerton, Palo Alto, CA, USA), whereas whole capillary blood glucose was measured using a photometric analyzer (HemoCueGlucose 201+, advanced medical technologies, Meaux, France). Insulin was determined by a radio-immunoassay (RIA Diagnostic, Pasteur, Marnes La Coquette, France). The antibody used in the test showed crossreactivity of 100% with human insulin and of 40% with proinsulin. Plasma triacylglycerols and FFA were measured with Biomérieux kits (Marcy-l'Etoile, France), and total cholesterol with Labintest kits (Aix-en-Provence, France). All samples were assayed in the same batch.

Calculation of GI

The incremental area under the plasma glucose curves (AUC) determined for each test (glucose or breads) according to standardized criteria, excluding area beneath the baseline, was calculated geometrically (FAO/WHO, 1998; Wolever *et al*., 2003). The AUC for the glucose test was used as the reference value and subject's GI for each kind of bread was calculated. The GI for each food was taken as the average of all nine individual values. GI was calculated as described by Wolever (2004). Similarly, the AUC for insulin was calculated after the different tests and the II was calculated. The AUC for plasma triglycerides and FFA were also calculated.

Statistical analysis

The validity of the crossover design was tested by an analysis of covariance of the baseline results (time 0) before consuming the respected experimental tests. Repeated measures analysis of variance (ANOVA), followed by a Bonferroni's adjustment, were used to compare glucose, insulin and lipid responses as well as the GI and the II in the healthy subjects. Student's *t*-test for paired data was used to compare the results of the two breads in T2D subjects.

All the statistics were carried out with JMP statistics software (SAS Institute Inc., Cary, NC, USA). Results were considered significant when $P<0.05$. Data are expressed as mean $\pm$ s.e.m.

Results

First study: in healthy subjects

Plasma glucose and insulin responses. Before consuming the different tests (glucose, CB, TB, Sand, Yeast-B, Leaven-B, WM-B), basal fasting plasma glucose (4.77 ± 0.11, 4.72 ± 0.06, 4.66 ± 0.16, 4.72 ± 0.06, 4.66 ± 0.11, 4.77 ± 0.11, 4.77 ± 0.06 mM, respectively, $P>0.05$) and insulin levels (6.90 ± 1.03, 6.11 ± 0.80, 5.83 ± 0.98, 6.12 ± 0.91, 6.84 ± 1.22, 6.50 ± 0.91, 6.80 ± 0.91, 6.78 ± 1.21 μU/ml, respectively, $P>0.05$) were comparable.

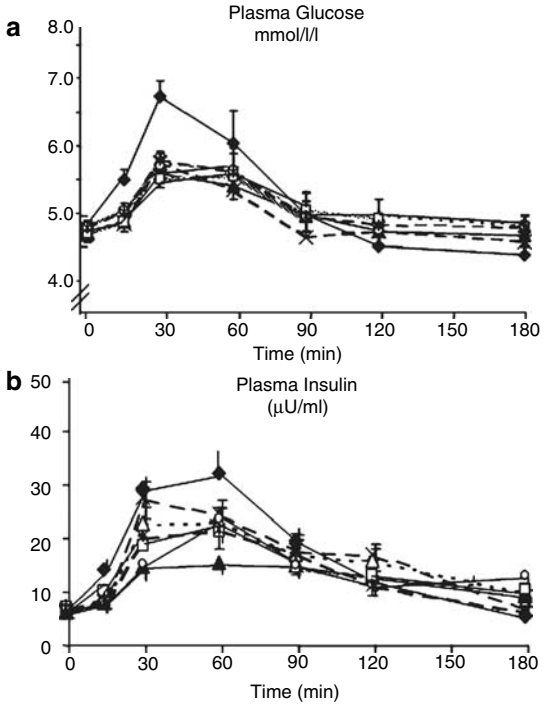

Figure 1 Plasma glucose (**a**) and insulin (**b**) responses to a 50 g oral glucose or an equal CHO challenge of tested breads in nine healthy subjects after an overnight fast. Classic baguette ·····△·····, traditional baguette —▲—, WM-B —*—, loaf fermented with yeast —□—, loaf fermented with leaven —○— and glucose challenge —◆— and sandwich —**X**—.

As shown in Figure 1, after the ingestion of 50 g glucose challenge plasma glucose was higher than the levels reached by the different tested breads at 30 min. At 120 min, the high postprandial plasma glucose peaks dropped to reach levels lower than baseline values. The postprandial responses to the different breads showed similar profiles. The AUC after glucose challenge was also significantly higher than AUC after the different kinds of bread. The GI of the tested breads are shown in Table 3. We were unable to detect any significant difference between the different kinds of bread.

Plasma insulin responses followed the glucose responses (Figure 1). The highest level of insulin was reached after 60 min of glucose ingestion. No statistically significant difference was observed among the responses of various tested breads, except that for the TB that was lower than the other breads at 60 min ($P<0.05$). The insulin AUC after the TB was significantly lower than that after the CB ($P<0.01$, ANOVA). The IIs of the various breads are shown in Table 3. The TB and the loaf fermented with leaven had the lowest II ($P<0.05$ vs classic baguette and sandwich).

Plasma triglycerides and FFA responses. The different breads resulted in comparable plasma triglyceride responses, with a tendency to be slightly elevated after the sandwich (Figure 2). When all the breads compared together at each time point, there were no significant change in plasma FFA at any time of the test (ANOVA, *P*-value between 0.19 and 0.08). When the traditional and classic baguettes were compared separately, plasma FFA decreased significantly at 90 min ($P=0.035$) and tended to drop more with the CB than with the TB at 60 min ($P=0.09$), at 120 min ($P=0.076$) and at 180 min ($P=0.15$) (Figure 2).

Second study: in type 2 diabetic subjects

All the patients had high basal fasting plasma glucose levels that remained comparable before the three tests (capillary 'C' samples: 8.8 ± 0.8 mM, 8.6 ± 0.8 mM and 8.2 ± 0.5 mM for glucose, traditional baguette and classic baguette test, respectively, $P=0.36$; venous 'V' samples: 9.6 ± 1.1 mM, 9.4 ± 1.0 mM and 9.3 ± 0.7 mM, respectively, $P=0.61$). The two breads had similar postprandial glucose profiles (both C

Table 3 GI and II values for the different tested French breads in healthy subjects

	Classic baguette	*Traditional baguette*	*Loaf fermented with yeast*	*Loaf fermented with leaven*	*Wholemeal loaf*	*Sandwich*[a]
GI	78 ± 17	57 ± 9	81 ± 35	80 ± 18	85 ± 27	59 ± 16
II	90 ± 15	50 ± 7*	71 ± 15	59 ± 7*	78 ± 21	100 ± 19

Abbreviations: GI, glycaemic index; II, insulinaemic index.
*Significantly different vs classic baguette, $P<0.05$ values are mean $\pm$ s.e.m. $n=9$.
[a]Classic baguette + ham + 10 g butter.

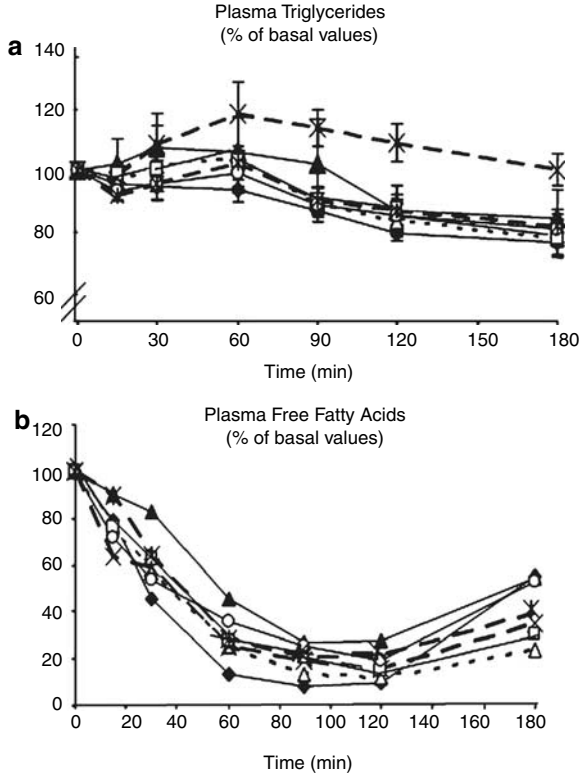

Figure 2 Plasma FFA (**a**) and triglyceride (**b**) responses to a 50 g oral glucose or an equal CHO challenge of tested bread in nine healthy subjects after an overnight fast. Classic baguette -----△-----, traditional baguette —▲—, WM-B —*—, loaf fermented with yeast ——, loaf fermented with leaven —○—, glucose challenge —◆— and sandwich —**X**—.

and V samples). The GIs of all the subjects were lower with the traditional baguette than with the classic baguette, but this decrease did not reach significant level (Table 4). However, when looking to the difference of the GI values between the traditional and the classic baguettes at the individual level (Table 4), an increase of 17 U (V blood) and 48 U (C blood) was found for one subject. In all the other subjects, the GI of the traditional baguette was lower than that of the classic baguette. When this subject was excluded from the analysis, the mean GI values decreased (V sampling: −6; C sampling: −14) significantly for the traditional baguette compared to the classic baguette (V: $P=0.002$; C: $P=0.028$). This subject was the unique subject with only dietary treatment and without medications. He had the lowest basal fasting plasma glucose (glucose test: 7.05; BC: 7.15; BT: 7.10 mM for venous sampling; and 6.93, 6.77 and 6.71 mM, respectively, for capillary sampling) and AUC after all the tests that might be influenced more easily by any small analytical error than in the other subjects. There was no significant difference between the mean GI values of the same breads measured by different blood sampling (traditional baguette: $P=0.65$; classic baguette: $P=0.13$, venous vs capillary samples).

Discussion

The present study demonstrated for the first time a comparison between postprandial plasma glucose and insulin responses after the ingestion of a variety of typical French breads. The mean GI value varied between 57 for the

Table 4 Individual GI values of TB and CB measured in T2D subjects from either venous or capillary blood sampling (glucose = 100)

Method	*Venous samples*			*Capillary samples*		
T2D subjects	*GI-TB*	*GI-CB*	*GI difference (TB-CB)*	*GI-TB*	*GI-CB*	*GI difference (TB-CB)*
S1	80	85	−5	88	103	−15
S2	66	76	−10	58	105	−47
S3	102	85	17	115	68	48
S4	85	87	−2	91	95	−4
S5	75	81	−6	74	89	−14
S6	73	80	−7	65	78	−13
S7	60	70	−10	57	66	−9
S8	55	58	−3	53	61	−8
S9	64	67	−3	63	64	−1
All[a]: Mean ± s.e.m. (s.d.)	73 ± 5^{A} (14.4)	76 ± 3^{A} (9.8)	−3 ± 3 (8)	74 ± 7^{A} (21)	81 ± 6^{A} (17)	−7 ± 8 (24)
P-value: TB vs CB		0.27			0.41	
Without S3[b]: Mean ± s.e.m. (s.d.)	70 ± 4^{A} (10)	75 ± 4^{B} (9)	−6 ± 1 (3)	69 ± 5^{A} (14)	83 ± 6^{B} (17)	−14 ± 5 (14)
P-value: TB vs CB		0.002			0.028	

Abbreviations: CB, classic baguette; GI, glycaemic index; II, insulinaemic index; TB, traditional baguette; T2D, type 2 diabetic.
[AB]Values in the same horizontal line with different letter superscripts differ significantly.
[a]Means for all subjects ($n=9$).
[b]Means for eight subjects (subject no. 3 was excluded).

traditional baguette and 85 for the wholemeal loaf. These values, however, did not differ significantly in normal subjects. Surprisingly, the TB was found to have significantly the lowest postprandial insulin response and the lowest II.

The physiological relevance of the GI for ranking in normal healthy subjects has been questioned, as healthy subjects can always maintain their plasma glucose level within a very narrow range, because it is tightly regulated by homeostatic regulatory systems. The relative hyperglycaemia, following the ingestion of high-GI meal, acts in concert with high gut hormones glucagon-like peptide-1 and glucose-dependent insulinotropic polypeptide to stimulate insulin secretion promoting hence the uptake of glucose by muscle and adipose tissue (Ludwig, 2002). This equilibrium, when works well as in healthy subjects, masks the differences in plasma glucose responses to a CHO challenge. In this group of subjects, plasma insulin responses are more relevant than the glycaemic responses as has been found in the present study. In T2D subjects, however, owing to impaired insulin secretion and consequently the lost of the strict control of plasma glucose levels, glucose responses are more pronounced. This hypothesis is entirely in accordance with the results of the present study: in diabetic patients, once the data from one atypical subject had been removed, the traditional baguette resulted in significantly lower GI value than the classic baguette. The type of blood sampling, being venous or capillary, did not influence the outcome in terms of GI. It has been reported that capillary blood may induce less within-subject variation in normal healthy subjects (Wolever *et al*., 2003). In diabetic subjects of the present study, however, this difference in variability was not observed. The reason for this might be due to the fact that, in the present study, diabetic subjects tightly respect their medications and dietary regimen.

An important point in this study is that all the tested French breads and especially the classic baguette had lower GI values than that of glucose in healthy subjects. This is in apparent contradiction with the unique study published (Bornet *et al*., 1987) on the classical French baguette, where GI was found to be 95%, and has been used as a reference in the national and the international citations (Foster-Powell *et al*., 2002). The reason for this difference may be due to the fact that previously (Bornet *et al*., 1987), the quantity of available CHOs was taken from published data in the 1990s (Documenta-Geigy, 1972) and considered to be 50/100 and not 60/100 g as had been found in the present study. Therefore, the quantity of available CHO was probably underestimated and the portion size was higher than that in the present. The mean GI of CB, in the present study, is comparable to the GI of other local white breads evaluated in an interlaboratory study (Wolever *et al*., 2003).

Concerning the WM-B in the present study, the fibre content of the tested bread was higher (5.6/100 g) than the other kinds of bread (1–2.9/100 g) but had no significant effect on glucose and insulin responses. The effect of fibres on plasma glucose levels has been well documented (Jenkins *et al*., 1978; Jenkins *et al*., 2002). Recently, Juntunen *et al*. (2003a, b) compared different kinds of rye bread with increasing concentrations of soluble and insoluble fibres. They did not find a relationship between the total fibre content of the tested rye bread (even 24/100 g insoluble fibres with 4.8/100 g soluble fibres) and the induced postprandial insulin responses. Plasma glucose and insulin responses were found to be affected by soluble and not insoluble fibres (Chandalia *et al*., 2000). In longer-term trials, high-fibre diets (40–65 g/day with high amount of soluble fibre from legumes) have been shown to improve diabetes control in type 1 diabetic subjects (Giacco *et al*., 2000), but not in type 2 diabetic subjects (Jimenez-Cruz *et al*., 2004). Moreover, dietary fibre is not a reliable predictor of postprandial plasma glucose, particularly in respect of flour-based products. Most WM-Bs and high-fibre breakfast cereals have high GI values that are similar to their refined counterparts (Foster-Powell *et al*., 2002). Therefore, in the present study, the presence of about 5 g fibre in the portion size tested for the WM-B was not sufficient to decrease postprandial glycaemic and insulinaemic responses.

The interesting result in the current study is the capacity of the traditional baguette and the Leaven-B to produce lower insulin responses than did classic baguette in healthy subjects. For the Leaven-B, the presence of certain organic acids produced upon sourdough fermentation may explain the lowering of insulin responses (Ostman *et al*., 2005). Previously, it had been demonstrated that sourdough decreased glucose and insulin responses by delaying gastric emptying rate (Liljeberg and Bjorck, 1996).

Concerning the traditional baguette, there is no apparent explanation to the reduced insulin responses, in healthy subjects, and glucose responses, in T2D subjects. The wheat flour used to prepare this bread was the same as that of the CB, but without ascorbic acid or other additives. High acidity (28 mM acetic acid) might lower the glycaemic and insulinaemic responses (Ostman *et al*., 2005). The absence of ascorbic acid, however, is unlikely to be implicated in decreasing insulin responses. Similarly, the fibre content of the bread could not be implicated, as the fibre content of the traditional baguette was comparable to that of other breads (with the exception of wholemeal French bread).

In an attempt to understand the underlying reasons leading to these results, we examined closer the methods used to prepare this bread. The traditional French bread was prepared by an artisanal procedure: owing to the presence of small quantity of yeast (only 1 g/100 g instead of 2.5 g/100 g for the other breads) a longer period was needed to complete its fermentation. Moreover, this bread had followed also a special kneading protocol (slow mixing for 10 min followed by 3 min of rapid mixing) that was totally different from other types of bread. Thus, it was the artisanal method in preparing this bread that prevented the dough to rise at its maximal capacity, modifying thus the texture of the bread: the crumb was more rigid, tense and with irregular alveoli (unpresented results). These texture modifications might

decrease the availability and the digestion of starch. This is likely, since recently it has been demonstrated that processing is important in increasing or decreasing the levels of the bioactive compounds in grains and modify also their bioavailability (Slavin *et al*., 2001). These results are in agreement with those of Juntunen *et al*. (2003a, b) demonstrating that a lower insulin secretion after the ingestion of rye bread than after the ingestion of wheat bread could be explained by difference in the structural properties of the two breads.

Interestingly, the low plasma insulin responses of the traditional baguette in the present study were associated with a tendency to increase plasma FFA during the postabsorptive phase, whereas the high insulin levels following the ingestion of the classic baguette were associated with low FFA responses. Increasing postprandial glucose and insulin responses are most effective in suppressing FFA (Kiens and Richter, 1996), owing to the antilypolitic effect of insulin, and hence increasing hunger. These results raise the possibility of a beneficial effect of the traditional baguette on satiety, as the absence of a high level of suppression of FFA in the postabsorptive state might increase satiety and decrease food intake during the following meal.

We concluded that contrary to previous reports, some varieties of French breads have lower II in normal subjects and lower GI in T2D subjects than other varieties. These differences might be explained by differences in bread processing and or fermentation procedure rather than fibre or resistant starch content. Because bread is an essential component of the daily diet, attempts should be made to decrease white bread glycaemic and insulinemic responses.

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