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ORIGINAL CONTRIBUTION

Coffee does not modify postprandial glycaemic and insulinaemic responses induced by carbohydrates

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Abstract
Background Strong epidemiological evidence suggests that coffee consumption is associated with lower risk of type 2 diabetes. In postprandial studies, however, caffeine consumption has been associated with impaired glucose regulation.
Aim of the study To study the acute effects of coffee and caffeine-containing soft drinks on glycaemic and insulinaemic responses.
Design Twelve healthy volunteers were served each test food once and the reference glucose solution twice, containing 50 g of available carbohydrates, after an overnight fast at 1-week intervals in a random order. Capillary blood samples were drawn at 15–30 min intervals for 2 h after each study meal. The incremental areas under the curve (IAUC), glycaemic index (GI) and insulinaemic index (II), were calculated to estimate the glycaemic and insulinaemic responses.
Results Glucose and insulin responses of coffees with glucose containing 150 or 300 mg of caffeine did not differ from responses of pure glucose solution; the GIs were 104 and 103, and the IIs were 89 and 92, respectively. When a bun or sucrose and milk were consumed together with coffee, lower GI values and insulin responses were observed, reflecting the carbohydrate quality and protein content of the accompaniments. Sucrose-sweetened cola produced a high GI value of 90 and an II of 61.
Conclusions Coffee does not modify glycaemic and insulinaemic responses when ingested with a carbohydrate source. Therefore, there is no need to avoid coffee as a choice of beverage in GI testing.

Keywords Coffee · Glucose response · Glycemic index · Insulin response · Insulinemic index

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Introduction

Several epidemiological studies have demonstrated that frequent coffee consumption is associated with a lower risk of type 2 diabetes [1, 2]. However, acute caffeine ingestion has been associated with impaired glucose tolerance. A glucose solution combined with caffeine capsules, typically 200 mg, or an infusion of caffeine of ~5 mg/kg body wt, elicited greater blood glucose and insulin responses than glucose alone [3–9]. Only, a few studies have focused upon how caffeine in a coffee drink affects postprandial glucose and insulin responses, and the published findings are inconsistent. Some studies suggest that coffee does not significantly affect 2-h postprandial glucose responses in healthy subjects [3, 10–12], whereas some studies report that coffee significantly increases postprandial glycaemia and insulinaemia both in healthy subjects [13] and in subjects with type 2 diabetes [14].

Higher consumption of sugar-sweetened soft drinks has been associated with an increased risk of type 2 diabetes [15, 16]. The large amounts of high-fructose corn syrup in soft drinks rapidly raise blood glucose and insulin concentrations [17, 18]. To our knowledge, there are, however, no glycaemic index (GI) or insulinaemic index (II) values for cola-type soft drinks, published in peer review journals, except the values in international tables of glycaemic index [19] that are based on unpublished observations and personal communications.

The main aim of this study was to examine the effects of two different coffee portions with glucose and caffeine-containing soft drinks on postprandial glucose and insulin responses. Further objectives were to study how coffee and different accompaniments affect glucose and insulin responses.

Subjects and methods

Subjects

Twelve healthy volunteers, one man and eleven women (age 34.8 (SD 10.4) years and body mass index 21.9 (SD 2.5) kg/m^2) were recruited. One woman dropped out after the fifth visit for personal reasons. All subjects were habitual coffee drinkers (the average intake of filtered coffee was 392 mL/day). At baseline, all subjects had normal fasting plasma glucose ($\leq$5.3 mmol/L), as well as normal glucose tolerance following a 75 g oral glucose tolerance test (OGTT) [20]. Exclusion criteria were smoking, active gastrointestinal disease (e.g. coeliac disease), lactose intolerance, a first-degree family history of diabetes, and regular medication (oral contraceptives were allowed). For women, other exclusion criteria were pregnancy, breast feeding, a history of gestational diabetes, or the polycystic ovary syndrome.

The Ethics Committee of the Hospital District of Helsinki and Uusimaa approved the study, and informed written consent was obtained from all subjects prior to the study.

Study protocol

The subjects were served six test foods each containing 50 g of available carbohydrates (except artificially sweetened cola) once and the reference food, the glucose solution, twice at 1-week intervals in a random order. Resting metabolic rate with questionnaire data on physical activity at work and during leisure time was used to compose an individual standardized evening meal (55% of the total energy from carbohydrates) for each subject the evening preceding the study day to provide 15% of the subjects' calculated daily energy expenditure. The subjects were also asked to follow their usual diet throughout the study and to consume at least 150 g carbohydrates per day during 3 days before the test mornings.

The subjects were advised to avoid vigorous physical activity and not to drink alcohol during the day preceding the tests. In addition, they were asked to fast for at least 10 h after their standardized evening meal, to avoid exercise in the morning of the study, and to arrive at the clinic by car or public transportation.

In the study clinic, weight was recorded and a baseline finger-prick capillary blood sample was taken. Thereafter, the subject consumed the study meal within 10 min and gave further finger-prick capillary blood samples at 15, 30, 45, 60, 90, and 120 min after starting to eat.

Study meals

Six different test foods were tested: a small coffee containing 150 mg caffeine with a glucose solution, a large coffee containing 300 mg caffeine with a glucose solution or 48 g of sucrose and 50 mL of milk or a bun, and two soft drinks, sucrose-sweetened and artificially sweetened cola (Table 1). The glucose solution alone was used as the reference food. Each of the test meals, except the artificially sweetened cola, and the reference food was given as a portion providing 50 g of available carbohydrates. The volume of sucrose-sweetened cola providing 50 g of available carbohydrates was 450 mL. This volume contained 54 mg of caffeine as well as the 450 mL of artificially sweetened cola served in this study. The total liquid volume of all meals was standardized to 550 mL by the adjustment of water.

Chemical composition of the study meals

The chemical composition of the study meals and the evening meal was analysed by AnalyCen (Lantmännen Analycen Ltd., Tampere, Finland). The protein content was analysed according to Mod NMKL 6, Kjeltec (nitrogen × 6.25), and fats were analysed gravimetrically (NMKL 131: 1989). Free sugars (i.e. glucose, fructose, lactose, maltose, and sucrose) were measured by using an ion chromatograph system (Dionex, Sunnyvale, CA). Starch was analysed by using a modified Åman method [21]. The caffeine content of the coffees and soft drinks was analysed at the THL, using a method [22] based on liquid–liquid

Table 1 Nutrient composition and caffeine content of the study meals

	Small coffee with glucose solution[a]	Large coffee with glucose solution[b]	Large coffee with sucrose and milk[c]	Large coffee with a bun[d]	Sugar-sweetened cola[e]
Available carbohydrate	50	50	50	50	50
Sugars	50	50	50.4	14.2	50.1
Sucrose	<0.1	<0.1	48	<0.1	38.3
Glucose	50	50	<0.1	6.3	5.9
Fructose	<0.1	<0.1	<0.1	5.6	5.9
Lactose	<0.1	<0.1	2.4	0.6	<0.04
Maltose	<0.1	<0.1	<0.1	1.7	<0.04
Starch	–	–	–	35.8	–
Protein	0.4	0.7	2.2	7.7	–
Fat	<0.1	<0.1	2.0	7.0	–
Fibre	–	–	–	2.8	–
Caffeine (mg)	151	303	303	303	54[f]

Glucose solution containing 50 g available carbohydrates was used as a reference food

[a] Filtered coffee beverage 125 mL (7 g of ground coffee, Juhlamokka; Gustav Paulig Ltd) + 50 g glucose

[b] Filtered coffee beverage 250 mL (14 g of ground coffee, Juhlamokka; Gustav Paulig Ltd) + 50 g glucose

[c] Filtered coffee beverage 250 mL (14 g ground coffee, Juhlamokka; Gustav Paulig Ltd) + 48 g sucrose (Danisco Ltd) + full fat milk 50 mL, fat content 3.5% (Valio Ltd)

[d] Filtered coffee beverage 250 mL (14 g of ground coffee, Juhlamokka; Gustav Paulig Ltd) + 87 g bun (Viipaloitu Pullava, vehnäpitko; Fazer Bakery, Oululainen Ltd) containing 50 g available carbohydrates. Bun is mildly sweet Finnish sweet bread flavoured with crushed cardamom seeds. Main ingredients of plain bun are wheat flour, water, sucrose, fat, yeast, egg, and milk powder

[e] Sugar-sweetened cola beverage 450 mL, 50 g available carbohydrates (Pepsi; Hartwall Ltd)

[f] Artificially sweetened cola beverage (Pepsi; Hartwall Ltd) 450 mL, 0 g available carbohydrates, contained the same amount of caffeine than sucrose-sweetened cola

extraction and high-performance liquid chromatography, HPLC (Agilent Eclipse XDP-C18, Palo Alto, CA, USA), and measured with a UV detector (Agilent 1100 Series, Palo Alto, CA, USA). The nutrient composition and caffeine content of the study meals are shown in Table 1.

Laboratory analysis

Glucose concentration in capillary blood was determined directly by using a glucose meter (HemoCue 201; HemoCue Ltd, Espoo, Finland). A quality-control solution recommended by HemoCue was measured twice every study morning; the CV of these measurements was 1.5%. Capillary blood samples (500 μL) collected in non-heparin gel tubes were allowed to clot at room temperature. Then, samples were centrifuged (4,000 × g; 15 min) and stored at −70 °C until an analysis of serum insulin was conducted at the THL. Insulin was analysed by the AxSYM system, which is based on the Microparticle Enzyme Immunoassay (MEIA) technology (Abbott Laboratories, Abbott Park, IL, USA). The inter-assay coefficient of the variation (CV) of insulin was 7.3% (low level control, 28 mU/L (200.9 pmol/L)) and 6.1% (high level control, 127 mU/L (911.23 pmol/L)). The sensitivity of the insulin assay was 1.0 mU/L (7.175 pmol/L).

Calculation and statistical analysis

The incremental areas under the curves (IAUCs), ignoring the area beneath the fasting concentration, were determined for both capillary glucose and insulin. The glycaemic and insulinaemic indices were calculated by using the glucose solution as the reference (GI = 100 and II = 100). Eleven insulin curves that included one or more strongly or three or more mildly haemolysed serum samples were excluded from the analyses. The statistical analysis was performed by using PASW Statistics 17.0 for Windows (SPSS Inc., Chicago, IL, USA). The results are expressed as means with their standard errors. The statistical significance of difference was assessed by applying the non-parametric Wilcoxon test with Bonferroni corrections. P values < 0.05 were considered significant.

Results

The small (150 mg caffeine) and the large (300 mg caffeine) coffee portions with 50 g glucose produced similar glucose responses as the reference glucose solution, resulting in a GI of 104 and 103, respectively (Fig. 1; Table 2). Thus, the twofold difference in caffeine content between the coffee portions did not affect the glucose IAUCs. The coffee

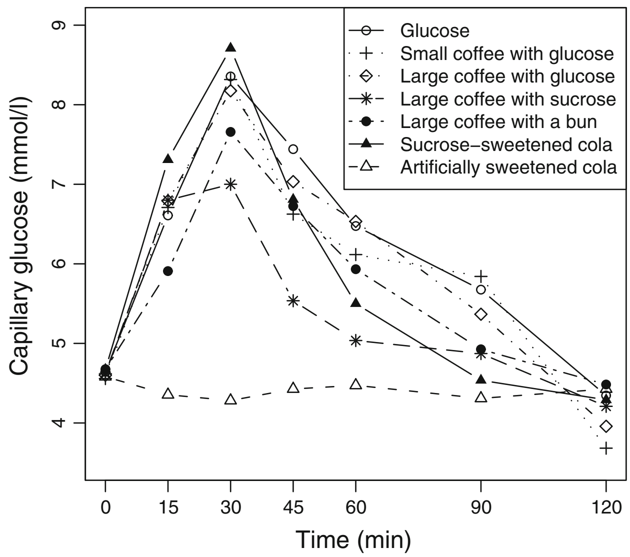

Fig. 1 Mean fasting and postprandial capillary blood glucose responses to the study meals over 120 min. All tests were 50-g portions of available carbohydrates, except artificially sweetened cola. $n = 12$ for all *curves*, except large coffee with sucrose and milk, sucrose-sweetened cola, and artificially sweetened cola where $n = 11$

portions with glucose solution yielded similar insulin IAUCs as that of pure glucose solution (Table 2).

The large coffee portion with sucrose and milk produced a medium GI value of 58 (Table 2). The insulin IAUC was moderate resulting in an II of 62 (Table 2). By contrast, coffee with a bun produced a slowly rising blood glucose concentration resulting in a medium GI value of 69 (Fig. 1; Table 2). However, it produced moderate insulin IAUC, resulting in an II of 73, but neither glucose IAUC nor insulin IAUC differed significantly from that of pure glucose solution (Fig. 1; Table 2).

The sucrose-sweetened cola drink sharply raised the glucose level (Fig. 1). At the 15 min blood sampling, the average blood glucose level had increased 0.7 mmol/L more than that of the glucose solution ($P = 0002$). Nevertheless, after 30 min, the blood glucose concentration rapidly fell and reached the fasting concentration at 90 min. The GI value for sucrose-sweetened cola was 90 (Table 2). However, the insulin response of the sucrose-sweetened cola was smaller than the glucose response, resulting in a moderate II of 61 (Table 2). Since the artificially sweetened cola sample did not contain available carbohydrate, it produced flat glucose and insulin curves (Fig. 1).

Excluding the outliers for GI values using a standardized method (outside mean ± 2 standard deviation) [23], the GI values for study beverages were 92 for the small coffee with 50 g glucose; 92 for the large coffee with 50 g glucose; 48 for the large coffee with sucrose and milk; 62 for the coffee with a bun; and 72 for sucrose-sweetened cola, respectively.

Discussion

In the present study, we tested the postprandial responses of two different portions of coffee with 50 g glucose added.

Table 2 Incremental areas under curves (IAUCs) for glucose and insulin, and glycaemic indices (GIs) and insulinaemic indices (IIs) by the study meals

Study meal	Glucose (mmol/L × 2 h)		GI[a]		Insulin (pmol/L × 2 h)		II	
	n	Mean ± SEM	*n*	Mean ± SEM	*n*[b]	Mean ± SEM	*n*[c]	Mean ± SEM
Glucose solution	12	207 ± 15		100	7	13,314 ± 1927		100
Small coffee with glucose solution	12	191 ± 17	12	104 ± 15	11	11,086 ± 1254	6	89 ± 9
Large coffee with glucose solution	12	193 ± 14	12	103 ± 13	12	11,640 ± 1531	7	92 ± 12
Large coffee with sucrose and milk	11	101 ± 9[d]	11	58 ± 11	9	6,843 ± 1,819	6	62 ± 11
Large coffee with a bun	12	133 ± 15	12	69 ± 9	11	10,270 ± 1,618	7	73 ± 8
Sucrose-sweetened cola	11	156 ± 11	11	90 ± 20	10	7,123 ± 1120	7	61 ± 14
Artificially sweetened cola	11	5 ± 3[d]	11	n.a.[e]	10	427 ± 125	7	4 ± 1

SEM standard error of the mean

[a] When the outliers for GI values were excluded (outside mean ± 2 standard deviation), the GI values for study beverages were 92 ± 9 (±SEM) for the small coffee with 50 g glucose; 92 ± 7 for the large coffee with 50 g glucose; 48 ± 6 for the large coffee with sucrose and milk; 62 ± 6 for the coffee with a bun; and 72 ± 7 for sucrose-sweetened cola, respectively

[b] Five subjects were excluded because of haemolysis in one of the glucose reference IAUCs. The insulin IAUCs of the glucose reference were calculated as the mean of twice repeated IAUCs of the reference food. Six IAUCs of the test foods were excluded because of haemolysis. One subject dropped out after the fifth visit; therefore, the IAUCs for three test foods are missing

[c] The IIs of the test foods are based on non-haemolysed IAUCs of the test foods and the twice repeated reference food

[d] Statistically significant from the respective reference food response, $P < 0.05$

[e] n.a. Not applicable, since the artificially sweetened cola contained no available carbohydrates

The portions were prepared using 7 or 14 g ground coffee, respectively, containing caffeine 150 and 300 mg. Both portions induced an equal glucose response that was similar to that of a pure glucose solution. Our results are consistent with earlier findings that suggest that coffee does not significantly affect 2-h postprandial glucose responses in healthy subjects [3, 10, 11]. There are, however, contradictory findings that report that coffee drinking compared to decaffeinated coffee significantly increases postprandial glycaemia during 2-h and, as a consequence, also increases the insulin responses both in healthy subjects [13] and in subjects with type 2 diabetes [14] after mixed-meal tolerance tests (MMTT).

Caffeine in capsules or through infusion decreased insulin sensitivity in healthy humans [3, 6, 9], in individuals with type 2 diabetes [7, 24], and in obese men [8]. The mechanism by which caffeine exerts its negative effects on glucose metabolism remains controversial. Inhibition of skeletal muscle glucose uptake has been suggested [5, 25] since caffeine is a known adenosine receptor antagonist [26]. It could also impair insulin-mediated glucose disposal by increasing plasma epinephrine concentration [5, 6, 9]. Our findings suggest that caffeine in coffee does not significantly alter postprandial insulin response. To our knowledge, only one study has compared the effects of caffeine capsules (4.45 mg/kg) and coffee with the same caffeine amount on insulin responses in a standard 2-h oral glucose tolerance test [3]. The coffee produced almost a 20% lower insulin response as compared to that of caffeine capsules. These findings suggest that other components of coffee may improve glucose metabolism or attenuate the negative effect of caffeine. Recent evidence demonstrates that chlorogenic acid found in coffee may delay intestinal absorption [10, 27]. However, in the present study, two different portions of coffee produced similar glucose responses including the IAUCs from 0 to 30 min (data not shown).

Coffee with sucrose and milk produced a medium GI value of 58, which is consistent with the results of GI studies testing 50 g of sucrose [19]. Although milk lowers glycaemic responses through the insulinotrophic effects of milk protein [28], in our study, the amount of milk protein was only 1.5 g, so its effect on glucose and insulin responses was most likely small. When a bun was ingested with a coffee, it resulted in a medium GI value of 69, which is in keeping with bakery products of the same kind [19]. Thus, when coffee is ingested with sugar, milk, or bakeries, the GI of the servings is determined by the GIs of the accompaniments.

In the international glycaemic index table, an average GI value of 58 for sugar-sweetened cola-type soft drinks has been reported [19]. Similar GI values have been measured for sucrose [19]. Despite the high sucrose amount, the sucrose-sweetened cola produced a high GI value of 90 in our study. The difference between our and the reported values may be due to the different ingredients of cola-type soft drinks. In the present study, the sucrose-sweetened cola produced the smallest average insulin IAUC of carbohydrate-containing samples, which is consistent with earlier observations that sucrose produced a smaller insulin response than the glucose solution [29]. To our knowledge, there are no studies that have reported the II values for cola-type soft drinks before the present study. Artificially sweetened cola, which did not contain available carbohydrates, produced flat glucose and insulin curves. This also indicates that caffeine per se does not influence acute glucose and insulin responses.

In conclusion, the results of our study suggest that coffee does not modify acute glucose and insulin responses. The glucose and insulin responses to coffee with sucrose and milk or a bun reflect the carbohydrate quality and protein content of the accompaniments. There is also no need to avoid coffee as the drink choice in GI testing. Sucrose-sweetened cola used in this study rapidly raises the blood glucose concentration and produces a high GI value, but a moderate insulin response.

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