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Article

Method of Food Preparation Influences Blood Glucose Response to a High-Carbohydrate Meal

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Abstract: The aim of this study was to establish the blood glucose response to different cooking methods of pasta. Participants consumed three identical meals in a random order that were freshly cooked (hot), cooled and reheated. Blood glucose concentrations were assessed before, and every 15 minutes after ingestion of each meal for 120 minutes. There was a significant interaction between temperature and time ($F_{(8.46-372.34)} = 2.75$, $p = 0.005$), with the reheated (90 minutes) condition returning to baseline faster than both cold (120 minutes) and hot conditions. Blood glucose AUC was significantly lower in the reheated (703 $\pm$ 56 mmol·L^{-1}·min^{-1}) compared with the hot condition (735 $\pm$ 77 mmol·L^{-1}·min^{-1},$t_{(92)}$ = -3.36, $p_{\text{bonferroni}}$ = 0.003), with no significant difference with the cold condition (722 $\pm$ 62 mmol·L^{-1}·min^{-1}). To our knowledge, the current study is the first to show that reheating pasta causes changes in post-prandial glucose response, with a quicker return to fasting levels in both the reheated and cooled conditions compared with the hot condition. The mechanisms behind the changes in post-prandial blood glucose seen in this study are most likely related to changes in starch structure and how these changes influence glycaemic response.

Keywords: Pasta; Glycemic Index; Resistant Starch

1. Introduction

Dietary carbohydrates are a fundamental constituent of a balanced diet, contributing between 40-70% of energy intake [1], with people relying heavily on staple foods, such as pasta and rice for energy [2,3]. The digestion rates of carbohydrates are determined strongly by the proportions of sugars, starch, and fibre present within the carbohydrate. Refined and starchy carbohydrates are readily hydrolysed into their glucose components by pancreatic amylase and brush border enzymes in the small intestine, whereas dietary fibres (including resistant starch, RS) cannot be hydrolysed in the small intestine [4]. Starch that has undergone retrogradation – a process by which the glucose molecules in starch re-associate with each other in an irregular fashion post-gelatinisation [5] - is known to have a high RS content, and therefore will not be digested as effectively in the small intestine and will undergo fermentation by gut bacteria in the large intestine [6]. Therefore, foods with a high RS content produce a lower glycaemic response and are classed as having a lower Glycaemic Index (GI).

Low GI diets have numerous nutritional benefits and may be effective in management of metabolic syndromes such as obesity and type-2 diabetes mellitus (T2DM), as they produce a lower postprandial blood glucose response [7,8]. There is a body of evidence supporting the link between RS digestion and postprandial hyperglycaemia and insulinaemia, because RS-rich foods are harder to digest and therefore have a lower GI.

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The preparation of food can also influence the GI properties of a meal, with retrogradation of starch by cooling and reheating, increasing the amount of RS present [9]. However, there is a lack of published evidence in humans that supports the effect of cooking on glycaemic response to a high carbohydrate meal.

The aim of this study was to establish the blood glucose response to a pasta meal that was cooked and eaten hot; cooked and eaten after cooling or cooked, cooled and then reheated. We hypothesised that the cooked and eaten hot meal would produce the highest glycaemic response when compared to the other methods of preparation because of its disorganised, amorphous structure and swollen starch granules produced by gelatinization, with the cooked, cooled then reheated meal causing the lowest glycaemic response due to its repeated retrogradation from being cooked, cooled and then reheated.

2. Materials and Methods

2.1. Participants

Forty-five healthy young volunteers (age = 20-24 years) took part in this study. Participants were informed of the experimental protocol both verbally and in writing before giving informed consent. The study protocol was approved by the School of Pharmacy and Biomolecular Sciences Research Ethics Panel (approval number: PABS-REP-2017-05).

2.2. Experimental Conditions

Participants undertook each experimental condition in a random order decided by a random number generator, with each experimental visit separated by a minimum of 48 hours. Participants were instructed to refrain from performing any strenuous physical activity for 2 days prior to each experimental visit and attended the laboratory after an overnight fast.

2.3. Pasta Preparation

Three different preparations of white fusilli pasta (Asda Stores Ltd, Leeds, UK) with a simple Tomato and Basil Stir-in pasta sauce (Dolmio®, Mars Inc., Slough, UK) were tested in this study: hot, cold and reheated. Each participant was given 100g (dry weight) of pasta, which was cooked in water for 20 minutes, at a ratio of 566 ml of water to 100g of pasta, with 100g of pasta sauce. The hot pasta meal was freshly cooked, the cold pasta meal was cooked and chilled for 24 hours overnight in a refrigerator at 4°C in a sealed plastic container, while the reheated pasta meal followed the same treatment as the cold condition but was then reheated on the day of the experiment for 3 minutes in a 750 W microwave (Proline SM18) on the high setting, with stirring every minute. Each subject was provided with 250 ml of water with their meal, which they were asked to ingest within 15 mins [10].

2.4. Blood Glucose Responses

Capillary blood samples were collected by the participant by single use lancet from the fingertip before, and every 15 minutes for 120 minutes after ingestion of the meal. Whole blood glucose concentrations were measured using an automatic analyser (Accu-Chek Performa Blood Glucose Meter, Roche Diagnostics).

2.5. Calculations and Data Analysis

Area under the glucose curve (AUC) was calculated using the conventional trapezoid rule. Blood glucose response was analysed using a 2-way repeated measures ANOVA, and area under the curve was analysed using a 1-way repeated measures ANOVA (Jamovi v 0.9.5.12). Pairwise comparisons were conducted using a Bonferonni post-hoc correction ($p_{\text{bonferonni}}$). Data shown is mean ± standard deviation unless otherwise stated, with significance accepted if $p < 0.05$.

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3. Results

3.1. Preparation Method

There was a significant effect of the preparation method of the pasta ($F_{(2-88)} = 4.40$, $p = 0.015$), with blood glucose concentration significantly lower in the reheated condition (5.78 ± 0.91 mmol/L) than in the hot condition (6.03 ± 1.02 mmol/L, $t_{(88)} = 2.94$, $p_{\text{bonferroni}} = 0.013$). There were no differences observed between cold pasta (5.94 ± 0.95 mmol/L) and either hot ($t_{(88)} = 1.10$, $p_{\text{bonferroni}} = 0.820$), or reheated ($t_{(88)} = 1.83$, $p_{\text{bonferroni}} = 0.210$) pasta.

3.2. Time

Pasta ingestion caused significant increases in blood glucose regardless of the preparation method ($F_{(3.06-134.81)} = 59.97$, $p < 0.001$), with significantly increased blood glucose at each time point compared with previous time up to 30 minutes (Table 1).

Table 1. Post-prandial glucose response

Time (mins)	0	15	30	45	60	75	90	105	120
Hot	5.07	5.91^{B}	$7.10^{B,C}$	6.68^{B}	6.26^{B}	5.90^{B}	5.97^{B}	5.82^{B}	5.58^{B}
	[0.70]	[0.76]	[0.95]	[1.00]	[1.23]	[0.77]	[0.78]	[0.78]	[0.67]
Cold	5.16	5.68^{A}	$6.63^{B,C}$	6.58^{B}	6.09^{B}	6.04^{B}	5.72^{A}	5.72^{A}	5.63
	[0.57]	[0.94]	[1.08]	[1.17]	[0.91]	[0.91]	[0.66]	[0.58]	[0.65]
Reheated	5.05	5.82^{B}	$6.94^{B,C}$	6.47^{B}	5.85^{B}	5.57^{A}	5.56	5.46	5.33
	[0.44]	[0.71]	[0.92]	[0.97]	[0.93]	[0.74]	[0.62]	[0.63]	[0.59]

Data shown is mean [standard deviation]. All n = 45. A/B significantly different from baseline ($p < 0.05$ / $p < 0.001$). C significantly different from previous time-point ($p < 0.05$)

3.3. Preparation Method x Time Interaction

There was a significant interaction between preparation method and time ($F_{(8.46-372.34)} = 2.75$ $p = 0.005$). The reheated condition saw a faster return to baseline compared to both cold and hot conditions, with the reheated condition seeing a return to baseline values within 90 minutes, compared with 120 minutes in the cold condition, and the hot condition not returning to baseline by the end of the 2-hour period (Table 1). However, there were no differences at any time point between any condition (Figure 1).

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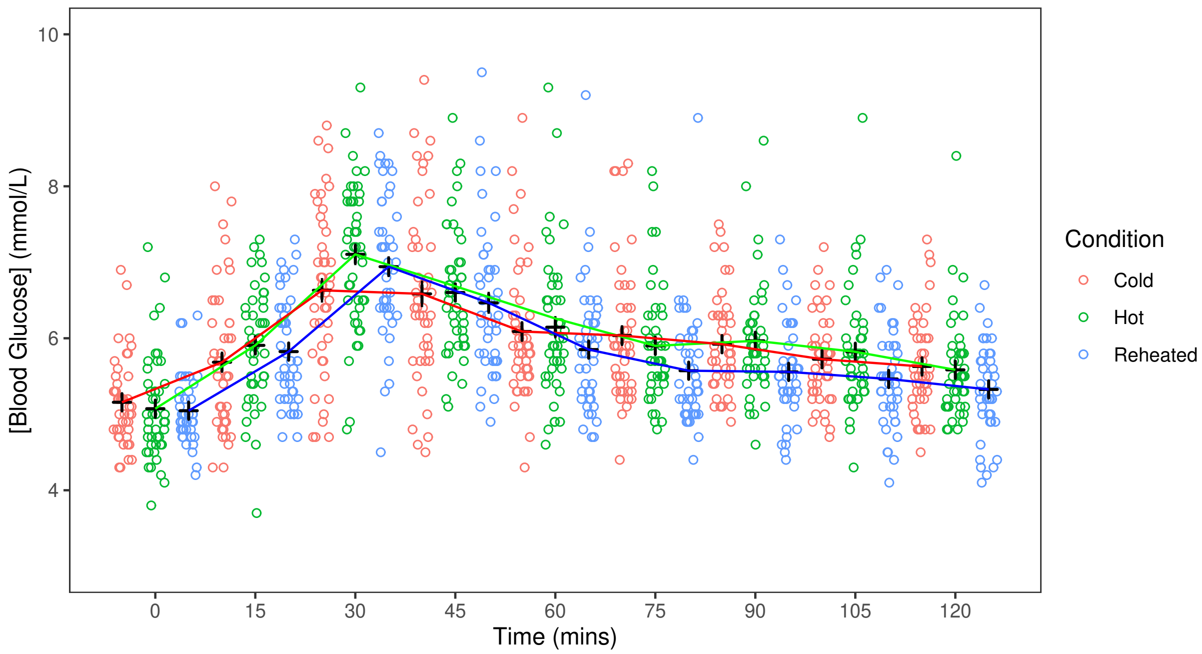

Figure 1. Post-prandial glucose response to either fresh (hot), cold, or reheated pasta. Data shown is mean ± standard error, alongside individual responses.

3.4. Area Under the Curve

There was a significant effect of preparation method on AUC ($F_{(2-92)}$ = 6.19, p = 0.003). Reheated pasta had a significantly lower area under the curve (703 ± 56 mmol·L^{-1}·min^{-1}) than the hot condition (735 ± 77 mmol·L^{-1}·min^{-1}, $t_{(92)}$ = -3.36, $p_{\text{bonferroni}}$ = 0.003), with no significant difference with the cold condition observed (722 ± 62 mmol·L^{-1}·min^{-1}, $t_{(92)}$ = -2.07 $p_{\text{bonferroni}}$ = 0.123). There was also no significant difference between the cold and hot condition ($t_{(92)}$= -1.29, $p_{\text{bonferroni}}$ = 0.601, Figure 2).

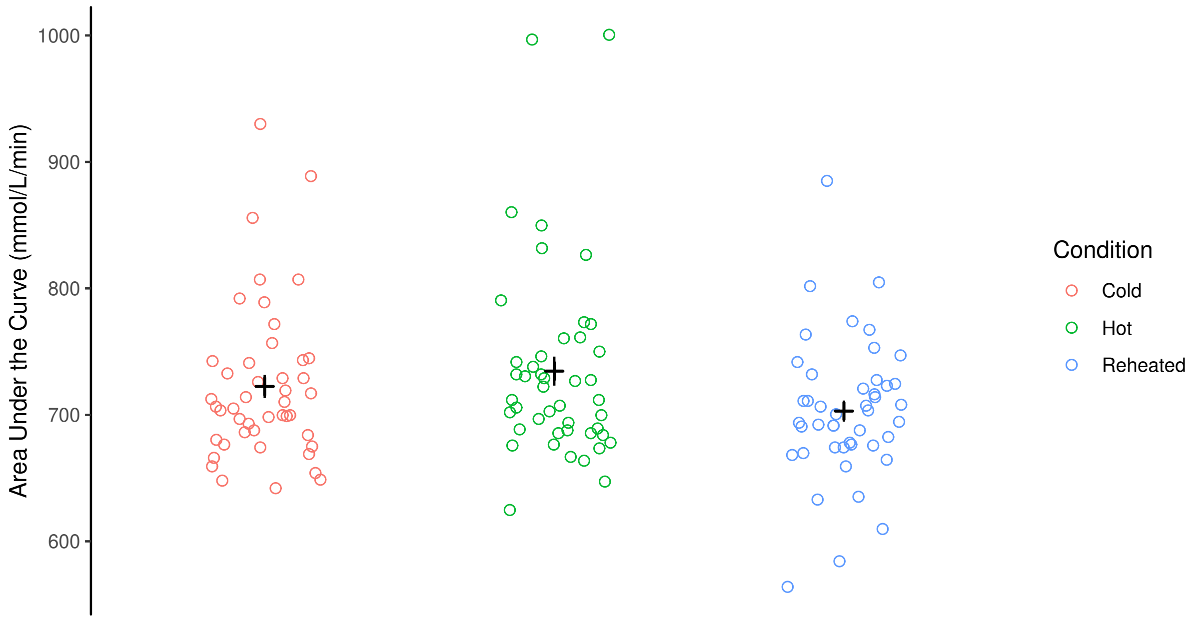

Figure 2. Area under the curve for post-prandial glucose response to three different carbohydrate meal preparations. Data shown is mean ± standard error alongside individual responses.

4. Discussion

This study aimed to examine the effect of cooking methodology of pasta on post prandial blood glucose, and found that both cooled, and reheated pasta, were associated with a faster return to baseline blood glucose, compared to the hot condition, while reheated pasta also showed significantly reduced blood glucose AUC, compared to freshly cooked pasta.

To our knowledge, the current study is the first to show that reheating pasta causes changes in post-prandial glucose response, with a quicker return to fasting levels in both the reheated and cooled conditions, compared with the hot condition. The mechanisms behind the changes in post-prandial blood glucose seen in this study are most likely related to modifications of starch structure and these subsequently influence glycaemic response. Studies in potatoes, noodles, rice and lentils indicate that cooking and cooling changes the amount of RS present [6,11–16] changing the digestibility of these foods [17,18]. This alteration in chemical structure, in conjunction with changes in amylopectin and amylose crystallisation, may contribute to the indigestibility of starch [19,20]. These retrograded RS molecules form tight structures stabilised by hydrogen bonds [5]. This modified structure means that digestive enzymes (*e.g.* α-amylase) less effectively digest starch [21] resulting in food with a lower GI [22].

Another important finding was that there was a significant effect of preparation method on AUC. Sonia et. al. [23] found lower blood glucose levels and AUC after consumption of reheated rice, compared with control rice, and suggested this was most likely attributable to higher RS, which would decrease the available carbohydrate content. A similar result was obtained by Lu et. al. [24], when comparing freshly cooked white rice with reheated cold-stored parboiled rice.

The decreased AUC resulting from reheating is significant because flattening the glucose response by reducing peak rise, reduces post-prandial glucose fluctuations, which has several benefits, such as the reduction of inflammation and oxidative stress, [25]. Schisano et. al. [26], reported that exposure of cultured endothelial cells to oscillating glucose concentrations was more deleterious than constant high glucose exposure and induced a metabolic memory after glucose normalisation, as well as causing greater apoptosis. In non-diabetic lean patients, reduced postprandial NFκB activation in white blood cells resulted from meals which elicited a flatter glycaemic response. [27]. In patients with T2DM glycaemic variability is implicated in coronary artery disease [28]. For example oxidative stress is activated by glycaemic fluctuations [29] and incremental glucose peaks have been shown to correlate with carotid intima-media thickness, which is a surrogate marker for atherosclerosis [30].

In conclusion, although it is evident that cooking methodology of pasta influences post-prandial glucose response, with a faster return to baseline in both cooled and reheated pasta, as well as reduced AUC following reheating, further work is needed to understand the mechanisms driving these changes and to ascertain if alterations in chemical structure is the primary factor influencing post-prandial glucose response.

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Abbreviations

The following abbreviations are used in this manuscript:

ANOVA	Analysis of Variance
GI	Glycaemic Index
AUC	Area under the Curve
T2DM	Type-2 Diabetes Mellitus

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