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ORIGINAL CONTRIBUTION

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Food intake and plasma ghrelin response during potato-, rice- and pasta-rich test meals

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Abstract *Objective* Complex carbohydrates such as potato, rice and pasta are frequently consumed accompaniments of meat meals and have different effects on satiety, food intake, glucose, and insulin concentrations. The orexigenic gastric hormone ghrelin contributes to feeding regulation and as yet it is unknown whether there is any differential ghrelin response to these starchy food items corresponding to their effects on food intake. *Methods* In 11 subjects the effect of satiating amounts of potatoes, rice or pasta consumed together with 150g pork steak was examined on hunger/satiety ratings, food intake, plasma insulin, glucose and ghrelin concentrations. *Results* All meals led to comparable quantities of food intake while energy intake was significantly lower after potatoes. Satiety/hunger ratings were significantly different from basal for the entire 4 h period after rice and pasta meals, while they had returned to basal during the 4th hour after potatoes. After rice and pasta insulin rose significantly for 4 h. Ghrelin decreased during the 2nd and 3rd hour. In contrast potatoes stimulated insulin for the initial 2 h only while ghrelin rose significantly by 120 pg/ml over the 4 h period. A significant correlation was observed between ghrelin and hunger ratings while subsequent second meal food and energy intake did not differ irrespective of the preceding ghrelin concentration. *Conclusion* Compared to rice and pasta satiating amounts of potatoes coingested with meat result in lower energy intake and postprandial insulin concentrations, which is not counterbalanced during subsequent food intake despite higher ghrelin concentrations. The present data support the concept that ghrelin can affect hunger sensations but not necessarily food and energy intake.

Key words insulin – satiety – hunger – food intake – energy density – carbohydrate – protein

Introduction

Obesity is an increasing health problem and responsible for a number of cardiovascular, metabolic and malignant diseases [49]. Therapeutic strategies of weight reduction are based on a decrease of energy intake apart from attempts to increase physical activity. On theoretical grounds the generation of a negative energy balance seems to be fairly easy, in daily practice however, results of various treatment

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modalities are rather poor, especially in view of the long-term weight reduction over several years [1].

Reduction of the fat content of ingested food is a widely used recommendation and has been shown to be helpful in weight reduction. On the other hand, carbohydrate overconsumption can be a problem in weight reduction programs [43, 48]. During main meals complex carbohydrates such as pasta, rice or potatoes are frequently consumed as a satiating accompaniment of meat. The satiety index of potatoes (323%) is more than twice the value of pasta (119%) or rice (138%) [24]. This would be an argument to favour the consumption of potatoes over the other two complex carbohydrates. On the other hand, the glycemic index (GI) of potatoes has been shown to be higher compared with rice and pasta and the greater availability of glucose is associated with an increased insulin response [6, 7, 23, 25]. Due to its potent lipogenic and antilipolytic properties an augmentation of insulin secretion favours weight gain and inhibits weight loss. In obese subjects carbohydrate ingestion leads to suppression of lipolysis over several hours [12]. Accordingly, high GI food items would seem to be rather inferior in weight reduction diets, which is supported by several studies [34, 35]. Considering these two aspects, satiety and insulin secretion, it seems difficult to give firm recommendations to obese subjects with regard to specific carbohydrate-rich food items as part of a mixed meal.

It must be noted, though, that the satiety studies of Holt et al. [24] have compared food items on an isocaloric basis which means that the ingestion of 368 g potatoes was compared with 201 g pasta and 203 g rice, respectively. The results of this study are in accordance with the concept that gastric filling and distension are an important mechanism for activation of satiety signals [10, 18, 38, 40–42]. In daily life, however, subjects eat until satiation is reached. Therefore we have examined food and energy intake during the ad libitum ingestion of pasta, rice and potato together with meat. In addition, insulin and ghrelin levels were determined. Ghrelin is a recently discovered orexigenic hormone which is predominantly secreted from the stomach and which stimulates appetite and food intake following i.v. administration [27, 46, 50, 51]. The postprandial ghrelin response depends on the nutrient composition of the ingested meals [8, 9, 13, 14, 47] and several studies support the concept that the rise of ghrelin during the later postprandial and interdigestive phase could contribute to the recurrence of hunger and appetite [8, 9, 14]. Therefore, it was of interest to see whether any differences of food intake might be related to differences of ghrelin release.

Subjects and methods

The experiments were performed in 11 male subjects (24.4 ± 0.3 years, BMI 23.5 ± 0.5 kg/m^2). None of the subjects had signs or symptoms of an acute or chronic disease or was taking any medication, and there was no family history of diabetes mellitus. All experiments were performed after informed consent was obtained. The study was approved by the institutional ethical review board in accordance with the guidelines of the ethical committee of the Technical University of Munich and in accordance with the principles of the declaration of Helsinki.

Experimental design

All subjects were instructed to consume a weight-maintaining diet containing 50% carbohydrate, 20% protein and 30% fat at least 2 weeks prior to and throughout the study period. All were non-smokers and were asked to refrain from alcohol consumption.

All experiments started at 8.00 a.m., after a 12 h overnight fast. An indwelling catheter was inserted into a forearm vein for collection of blood samples. On 3 separate occasions each subject received in random order with at least 2 days interval a test meal consisting of a fixed portion of 150 g lean pork steak (564 kJ/100 g; 83.0% protein, 17% fat, 0% carbohydrate, energy percent). Together with the meat all subjects were asked to consume white pasta (594 kJ/100 g; 79% carbohydrate, 13.9% protein, 7.1% fat), white rice (447 kJ/100 g; 90.5% carbohydrate, 7.9% protein, 1.6% fat) or potatoes (293 kJ/100 g; 86.9% carbohydrate, 11.8% protein, 1.3% fat) ad libitum until feeling comfortably satiated. Potatoes, rice and pasta were boiled in slightly salted water for 20, 20 and 10 min, respectively. They were served in 50 g portions seasoned with tomato sauce. Ratings of subjective feelings of hunger and satiety were made on 100 mm visual analogue scales (VAS) before and in 15 min intervals after starting meal consumption as described previously [5, 14, 16]. After 240 min all subjects were given a standard sandwich test meal consisting of bread, butter and ham (1141 kJ/100 g, 44.4% carbohydrate, 16.2% protein and 39.4% fat) which they had to eat until feeling satiated. Two days prior to the feeding tests the subjects were asked to rate the pleasantness of the test meals on a score between 1 (totally unpleasant) and 10 (very pleasant). Subjects who assigned a rating of 6 or less to at least one test meal or who had a difference of 3 or more between test meals were excluded from the study.

Blood samples were taken at −15, 0, 15, 30, 45, 60, 90, 120, 150, 180, 210 and 240 min, after the second meal samples were taken at 255, 270, 285 and 300 min. The

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samples were collected into plastic tubes containing 1.2 mg EDTA and 500kIU Trasylol for hormone analysis and into NaF-containing tubes for the determination of glucose. All samples were kept chilled in an ice bath until centrifugation at 2000 rpm for 15 min at 4°C. The separated plasma was stored at −20°C until the time of assay. All samples of one subject were run in duplicate in the same assay.

Plasma ghrelin concentrations were determined with a commercial radioimmunoassay, which has been employed in several previous studies [9, 13, 14] (Phoenix Pharmaceuticals, Belmont, CA). The assay uses ^{125}I-labeled bioactive ghrelin as a tracer molecule and a polyclonal antibody raised in rabbits against full-length octanylated human ghrelin, which detects both active and inactive ghrelin. The interassay coefficient of variation was 10%. The intraassay coefficient of variation was 4%. No cross-reactivity was observed with gastrin, somatostatin, GIP, GLP-$1_{(7\text{-}36)\text{amide}}$, neuromedin C, CCK and insulin, respectively. To convert ghrelin from pg/ml to pmol/l multiply by 0.302. Insulin concentrations were determined using a radio immunoassay from DPC, Los Angeles, CA (μU/ml × 7.18 = pmol/l). Glucose concentrations were measured by the hexokinase method (Roche-diagnostics, Mannheim, Germany) (mg/dl × 0.055 = mmol/l).

Statistical analysis

All data are expressed as mean ± SEM. Incremental levels for insulin, ghrelin and glucose were calculated for the 240 min postprandial period as the area under the curve (AUC) according to the trapezoid rule. For satiety and hunger ratings incremental levels were calculated for the five 60 min periods following the first meal and the 60 min period after the second meal. For statistical comparisons analysis of variance for multiple determinations within or between groups followed by post hoc Dunn's- or Tukey's-test, respectively, was employed. The relationship between parameters was examined by Pearson's Product moment correlation. *P*-values of 0.05 or less were considered to be significant. All data were analysed by using a commercially available statistic program (Sigma Stat, Jandel GmbH, Erkrath, Germany).

Results

Food intake

The consumption of satiating amounts of the three complex carbohydrates together with 150 g meat resulted in comparable quantities of food intake

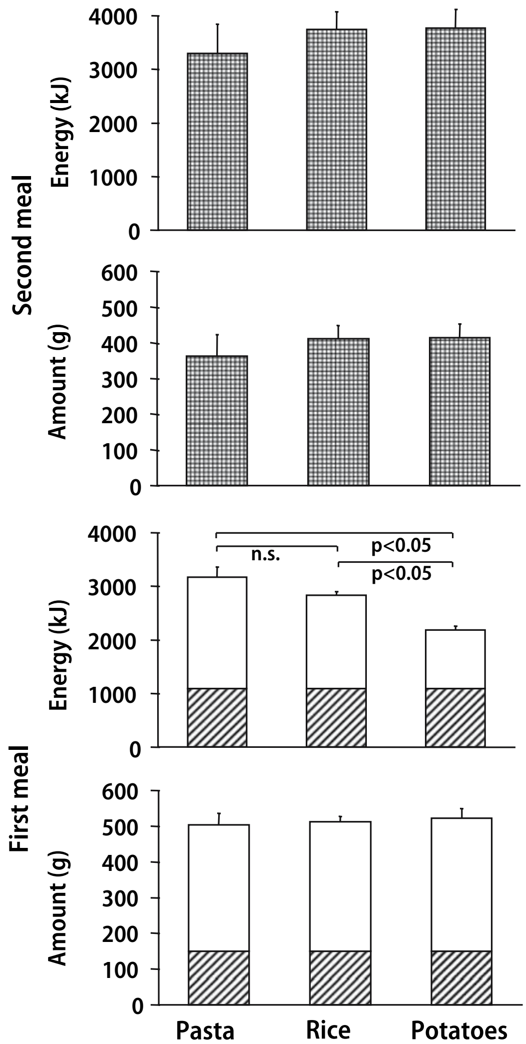

Fig. 1 Satiating amounts of food and energy intake consumed during the three test meals consisting of ad lib rice, pasta or potatoes together with 150 g pork steak (shaded = pork meat; open = carbohydrate component) at the start of the experiment (lower half). In the upper half food intake is shown during the second sandwich meal at 240 min after the respective preceding first test meal (n = 11, mean ± SEM)

(353 ± 32.1 g pasta, 362 ± 15.0 rice and 372 ± 27.8 g potatoes) (Fig. 1). Due to the different energy density of the three food items energy intake was significantly less with the potato meal (2177 ± 81.3 kJ) compared to pasta (3174 ± 189.4 kJ) or rice (2829 ± 72.3 kJ), respectively. With all three carbohydrate varieties the maximal increase of satiety as well as the maximal reduction of hunger sensations was reached within the first 60 min after onset of eating, remaining at this level during the second experimental hour and returning thereafter towards baseline. During the fourth hour there was still a significant degree of satiety and reduction of hunger when rice and pasta were eaten

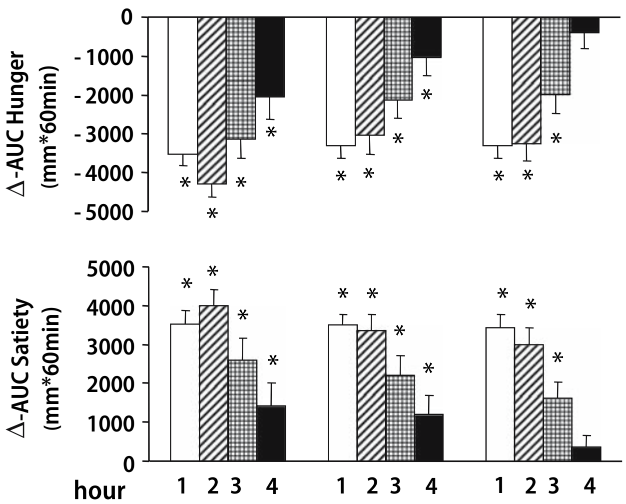

Fig. 2 Incremental hourly postprandial changes of hunger/satiety ratings during the first 240 min in 11 subjects during the three respective test meals (mean ± SEM). * Indicates significant differences of $P < 0.05$ or less versus the baseline period

while satiety and hunger feelings after potatoes were no longer different from baseline (Fig. 2).

Ingestion of the second meal at 240 min consisting of sandwiches revealed no significant differences irrespective of the preceding first meal (363 ± 59.9 g; 3305 ± 543.9 kJ after pasta; 411 ± 36.4 g; 3746 ± 331.2 kJ after rice; and 414 ± 39.4 g; 3768 ± 358.4 kJ after potatoes) (Fig. 1). Similarly hunger and satiety ratings were not different between the three groups.

Hormonal changes

Basal concentrations of insulin, ghrelin, and glucose prior to meal ingestion were not significantly different between the groups (Table 1). After the intake of pasta incremental plasma insulin was elevated for the 4 h experimental period with a maximum during the first and second postprandial hour declining thereafter (Fig. 3). Plasma ghrelin was significantly suppressed during the second and third hour while incremental glucose was elevated only in the first hour (Fig. 3).

The ingestion of rice together with meat led to a similar pattern as pasta. Insulin levels were above baseline for the entire 4 h period while ghrelin was decreased during the second and third hour only (Fig. 3). Following the ingestion of potatoes and meat plasma insulin was similarly elevated during the first hour. During the second hour insulin was lower compared to the other two meals and returned to baseline rapidly thereafter.

In contrast to pasta and rice potato ingestion was associated with unchanged plasma ghrelin during the

Table 1 Basal levels of plasma insulin, ghrelin and glucose prior to ingestion of the respective test meal (mean ± SEM)

	Insulin (μU/ml)	Ghrelin (pg/ml)	Glucose (mg/dl)
Pasta	0.6 ± 0.3	328 ± 53	89 ± 3.4
Rice	0.5 ± 0.2	360 ± 64	85 ± 2.7
Potato	0.2 ± 0.1	344 ± 41	83 ± 2.4

first two postprandial hours. Thereafter ghrelin increased reaching a maximum during the 4th hour (Fig. 3).

The incremental changes during the entire 240 min period following the first meal are shown in Fig. 4. The rise of insulin was significantly lower following the potato meal compared to rice and pasta. The increase of the plasma ghrelin response after potatoes was also significantly different compared to the suppression during rice and pasta.

Incremental insulin during the second meal calculated on the basis of the respective 240 min value was not significantly different in all three groups (pasta 592 ± 111.5; rice 807.7 ± 138.3 and potatoes 635.3 ± 88.7 μU/mL*60 min). As insulin the increase of glucose was comparable in all groups without any difference between groups (pasta 5932 ± 289.7; rice 5981 ± 150, potatoes 6011 ± 195.3 mg/dl*60 min). The decrease of plasma ghrelin by −2984.8 ± 1020.1 pg/ml*60 min after potatoes was significantly greater compared with the pasta group (−1135.0 ± 654.3 pg/ml*60 min; $P = 0.026$) but not with rice (−1353.1 ± 781.4 pg/ml*60 min, $P = 0.1$) although it must be noted that the preceding baseline value in the potato group was higher.

Relationship between ghrelin, hunger ratings and food intake

When all three-test meals were considered together fasting plasma ghrelin did not correlate with the caloric intake of the first meal ($r = 0.27$; n.s.). Ghrelin at 240 min correlated with neither subsequent meal size nor energy intake of the second meal ($r = 0.04$; $P = 0.8$). The relationship between changes of plasma ghrelin concentrations and hunger sensations was not significant during the 1st hour ($r = -0.12$, $P = 0.5$) but became progressively more significant during the subsequent time intervals (second hour: $r = 0.34$; $P = 0.05$; third hour: $r = 0.47$; $P = 0.006$ and fourth hour: $r = 0.54$; $P = 0.001$). No correlation of 4th hour subjective hunger ratings to the subsequent second meal food intake was found ($r = 0.05$, $P = 0.8$).

There was a significant inverse correlation between 4 h incremental ghrelin and energy density of the consumed test meals ($r = -0.488$, $P = 0.004$). There

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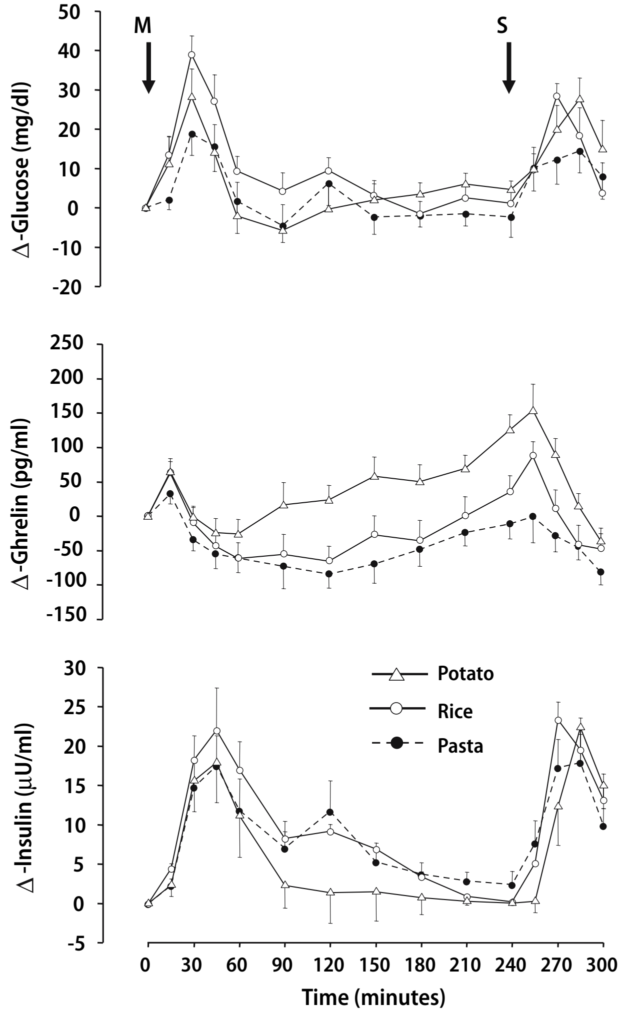

Fig. 3 Changes of plasma insulin (µU/ml × 7.18 = pmol/l), ghrelin (pg/ml × 0.302 = pmol/l) and glucose concentrations (mg/dl × 0.055 = mmol/l) from baseline following the ingestion of the three respective test meals **(M)** and the subsequent sandwich meal **(S)** (mean ± SEM, n = 11)

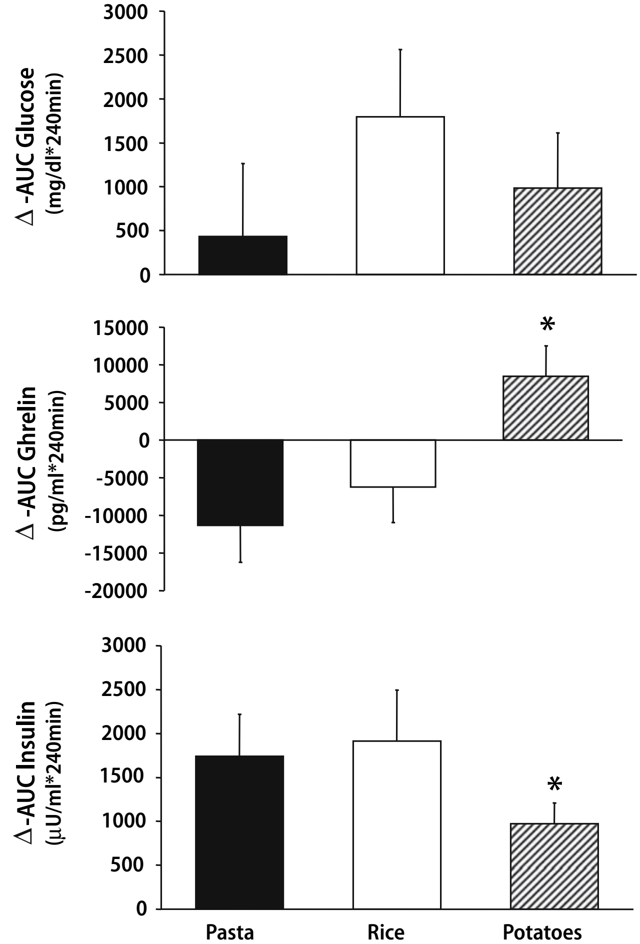

Fig. 4 Incremental plasma insulin (µU/ml × 7.18 = pmol/l), ghrelin (pg/ml × 0.302 = pmol/l) and glucose concentrations (mg/dl × 0.055 = mmol/l) over the 4 h postprandial period following the ingestion of the three respective test meals (mean ± SEM, n = 11). * Indicates significant difference of $P < 0.05$ or less versus the pasta and rice meal, respectively

was also a significant inverse correlation between ghrelin and insulin ($r = -0.498$, $P < 0.003$). The comparison of 4 h ghrelin as the dependent variable with energy density and 4 h insulin responses as the independent variables in a multiple linear regression analysis indicates that the ghrelin response can be predicted by energy density with $P < 0.01$ and by insulin with $P < 0.006$.

Discussion

Complex carbohydrates such as rice, pasta and potatoes are frequently consumed as a satiating component during main meals and they have an overall lower energy content compared to fat-containing food items of similar size. Despite this advantage compensatory carbohydrate overconsumption can be a problem in weight-reduction programs [43, 48].

In the present study ad libitum consumption of rice, potatoes and pasta led to an overall identical pattern of early hunger and satiety ratings till termination of first meal food intake. This was paralleled by comparable quantities of food intake. These findings indicate that the satiating efficacy of the three carbohydrates is identical. Furthermore, the data emphasize the importance of meal volume for generating satiety. Previous studies have shown that filling and distention of the stomach activates satiety signals [10, 18, 38, 40–42] and contributes to augmented release of anorexigenic neurotransmitters at central hypothalamic sites of feeding regulation [42]. Thus, energy intake depends on the energy density of the respective food items, which is supported by a number of short- and long-term feeding studies [3, 11, 12, 14, 19, 20, 26, 28, 30, 36, 38, 40, 44] and it is supported further by the present data. Thus, from the perspective of as little energy consumption as possible in conjunction with a sufficient food quantity potatoes are superior to rice or pasta, which extends the previous isocaloric studies by Holt et al. [24]. In addition, the present data demonstrate that the duration of satiety was less after potatoes. This, however, did not result in an increase of second meal food intake.

The present findings demonstrate that not all carbohydrate-rich food items have a suppressive effect on postprandial ghrelin concentrations. They support previous observations, which have shown that the acute postprandial decrease of gastric ghrelin secretion is most likely of none or only minor importance for early postprandial satiety since maximal satiety and trough ghrelin levels are approximately 1 h apart [4, 8, 14, 33]. All subjects had finished food intake within 30–45 min. At this time maximal changes of hunger and satiety ratings had been reached while ghrelin levels did not change significantly during this first experimental hour. Accordingly there was no statistical correlation between these parameters.

Furthermore, it had been hypothesized that the rise of ghrelin during the later postprandial and interdigestive phase could contribute to the recurrence of hunger and appetite [8, 9]. This concept is supported by several studies [4, 8, 33] while others did not find such a close relationship [14, 45]. The present data support the concept of ghrelin being a stimulus of hunger sensations during the later postprandial phase with a progressively better correlation coefficient. On the other hand, they do not favour a role of ghrelin for stimulation of subsequent meal size in view of the significant increase of ghrelin after the potato meal without any different second meal food intake compared to the other two feeding conditions. This observation is in accordance with previous studies that have observed a similar relationship [2, 8, 21, 31].

The reason for the different postprandial ghrelin pattern following potato ingestion remains unclear as yet. There was a significant and inverse correlation between ghrelin and energy density. In previous experiments the energy density of the meal in the absence of carbohydrate-induced insulin stimulation did not lead to greater suppression of ghrelin [13, 14]. On the other hand, there was an even better inverse correlation between insulin and ghrelin. Insulin and several gastrointestinal hormones have been shown to decrease gastric ghrelin secretion [15, 29, 32, 39]. The more rapid decline of postprandial insulin following the potato meal could in part contribute to the rise of ghrelin but other mechanisms cannot be excluded. It is noteworthy, that a similar ghrelin response with a maximal rise after 4 h has previously been observed after satiating amounts of mixed vegetables [14].

The glycemic index (GI) of potatoes has been shown to be higher compared with rice and pasta and the greater availability of glucose is associated with an increased insulin response [6, 7, 23, 25]. Due to its potent lipogenic and antilipolytic properties an augmented insulin secretion favours weight gain and inhibits weight loss. Especially for obese subjects further stimulation of already elevated insulin levels can be a substantial problem. Accordingly, high GI food items would seem to be rather inferior in weight reduction diets. In mixed diets the relevance of the glycemic index of the individual components is of minor importance since blood glucose levels are ameliorated due to changes of gastric emptying. The glycemic index of potatoes, rice and pasta is 80, 70 and 70, respectively when based on studies in normal subjects [17]. The glucose response in the present study was highest after rice followed by potatoes and pasta. Although the differences were not statistically significant the data support the notion that the glycemic index is of minor relevance and it does not explain the hormonal changes. Nevertheless the insulin response shows a positive correlation with high GI mixed meals [22]. The present data demonstrate that the early peak insulin response of the three carbohydrates is not different. When compared on the basis of satiating rather than isoenergetic quantities the absolute quantity of ingested carbohydrate is less in the potato meal (56 g vs. 94 g rice and 99 g pasta), which favours the shorter duration of hyperinsulinemia (2 h instead of 4 h). As outlined previously [37] this is another important aspect for the preference of food items with low energy density. Carbohydrates represent the largest quantity of the three macronutrients in virtually all-modern diets and they are important for the association of eating with satisfaction and related behavioural and emotional cues. Therefore, they should be selected carefully in terms of quantity and quality when treating obese subjects.

In conclusion satiating amounts of potatoes coingested with meat lead to lower energy intake and postprandial insulin compared to rice and pasta. The inverse ghrelin response after potatoes does not have a counterregulatory effect during subsequent food intake.

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