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Research Article | Journal of Nutritional Health & Food Science | Open Access

Effect of Different Isoenergetic Breakfast Compositions on Blood Glucose Regulation, Energy Allocation and Satiety

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Received: August 25, 2014; Accepted: September 06, 2014; Published: September 18, 2014

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Abstract

Background and purpose: The increasing prevalence of overweight and obesity among adults, demands improved dietary strategies for weight management and metabolic competence. Hence, the objective of this study was to assess the short-term effects of breakfasts with varying macronutrient composition on blood glucose regulation, energy metabolism and satiety.

Methods: This study examined ten healthy males (25.6 ± 4.4 yrs; BMI 23.2 ± 0.9 kg/m^2) fed isoenergetic breakfasts rich in either Carbohydrate [CH] (68% of energy), Fat [Fat] (64% of energy) or Protein [P] (35% of energy) or a breakfast which reflected the individuals Normal [N] breakfast composition. Blood glucose and lactate, resting oxygen consumption (VO_2), Respiratory Quotient (RQ) and satiety feeling were measured. All breakfasts with the exception of the individual normal breakfast variant were isoenergetic and all contained the same amount of dietary fiber. As a non-dietary control, subjects drank 200 ml water on one test day, with the same metabolic parameters measured.

Results: Compared with the water control day, there was a significant macronutrient-induced change in the metabolic parameters. The most significant increases in blood glucose were found after the Carbohydrate breakfast and the individual normal breakfast, whereas the Fat and Protein-rich breakfasts induced comparatively smaller blood glucose responses. Only the Protein-rich breakfast led to significant increases in resting VO_2 (up to 30%) without changes in RQ. Finally, the Protein-rich breakfast induced the highest satiety feeling.

Conclusions: Although the Protein-induced effects may initially appear minor, the combination of a reduced glycemic response, increased VO_2, a proportionately high fat oxidation and a stronger satiety effect may support the use of this dietary approach for healthy weight management in normal weight men.

Keywords: Macronutrients; Energy Metabolism; Satiety; Weight regulation

Introduction

An imbalance between energy intake and expenditure drives excess weight gain [1], with a long-term positive balance resulting in overweight and obesity. Numerous factors influence food and energy intake including exogenous factors such as food portion sizes macronutrient composition of the diet, as well as the social environment. Endogenous parameters include feelings of hunger and satiety, eating frequency and the psychology of individuals as well as their level of physical activity [2]. Taken together, these factors can prove to be challenging for individuals wishing to manage their body weight via a diet and lifestyle approach. Nevertheless a strong sensation of meal-induced satiety could be a key determinant of an individual's ability to achieve energy balance over the course of a day and in the longer term. Different foods and macronutrients vary in their satiety-inducing properties although it remains unclear if there is an optimal ratio of macronutrients within a meal to promote the most robust satiety response. Additionally, macronutrients also vary in their ability to increase metabolic rate and to influence post-prandial glycemia; both if which can influence the ability to maintain a healthy body weight. Indeed the latter has also been linked to poorer satiety response due to the concomitant insulin release. During eating, the feeling of satiety should appear well-timed to avoid excessive energy consumption. Ideally this regulatory mechanism should help maintain a healthy body weight in adults, however rising prevalence of obesity and other eating disorders suggest that the satiety mechanism fails or is being over-ridden in many individuals [3]. If an ideal macronutrient composition of a meal could be identified, it could be promoted to encourage people, to follow who wish to maintain a healthy body weight, as well as acting as a new strategy to help reduce body weight and body fatness in those who are already overweight or obese [4-6]. Thus the purpose of this study was to evaluate the short-term diet-induced effects of different test breakfasts on satiety as well as on blood glucose and lactate response, resting energy expenditure and RQ and hence fat oxidation over four hours post consumption.

Materials and Methods

Participants and recruitment

In this study, ten healthy male volunteers (25.6 ± 4.4 yrs; BMI,

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23.2 ± 0.9 kg/m^2) were recruited. All volunteers were within the healthy BMI range, non-smokers, free from known food allergies, metabolic diseases and none regularly used any medication. All volunteers were interviewed and screened before participating in this study at the Department of Sports Medicine of the Freiburg University Hospital.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Ethics Commission of Freiburg University (EK-Freiburg 143/03-110224). All participants started the study after providing written informed consent.

Screening

The screening involved anthropometric, physical and blood examinations as well as a performance diagnostic. Height was measured to the nearest 0.1 cm without shoes and body weight was measured utilizing a digital scale. Body Mass Index (BMI) was then calculated. Body density was predicted from skinfold thickness measurement using skinfold calipers (Lange Skinfold Caliper, Beta Technology Inc., Noblesville, USA) at 4 sites (m. biceps brachii, m. triceps brachii, suprailliacal, subscapular) and percentage fat mass was derived using the Siri equation. The performance diagnostic [7] was achieved using standardized and approved methods in the Department of Sports Medicine. Using a lactate analysis, the individual's relative VO_2max was calculated. Subjects' physical characteristics are presented in Table 1.

Study design

The effects of the participants' responses to the different diets were tested on five separate occasions following an overnight fast. Participants were asked not to consume any food or beverages except water after 11:00 pm the night before test days and refrain from exercise (beyond normal daily activities) and alcohol the day before and on the morning of the test days. Test variables were measured in the morning after fasting. A randomized scheme was used in which baseline and postprandial parameters were measured over a period of four hours after consumption of the test breakfast. The measurements were performed at intervals of at least one week. Each participant was tested on the same day of the week and at the same time of the day. On each test day, one of five breakfast variations was offered. Breakfasts were prepared freshly in the morning. Participants were instructed to eat and drink everything within 10 minutes. Water was allowed *ad libitum* throughout the test. Participants were assigned a sitting activity in the morning of the test day to avoid additional energy expenditure from physical activity.

Test meal

Breakfasts were either rich in Carbohydrate [CH] (68% of energy), fat [Fat] (64% of energy) or Protein [P] (35% of energy) Table 2. All breakfasts were approximately 700 kcal and similar in dietary fibre content (6.1 g – 6.4 g per meal). Additionally, the composition of each subject's individual habitual or Normal [N] breakfast was imitated and also designed to approximate 700 kcal/meal. As a control, participants received 200 ml water to drink on an additional test day. The compositions of the breakfasts are given in Table 3.

Test parameters

The state of satiety was recorded at determined time points across the study using a Borg scale [8]. Blood glucose and lactate concentrations were analyzed using an enzymatic amperometric glucose and lactate sensor (EBIO plus, EKF-diagnostic GmbH, Magdeburg). Resting oxygen uptake (VO_2) and Respiratory Quotient (RQ) were measured by indirect calorimetry using breathing mask with volume sensor of spiroergometry station (ZAN 600 USB CPX, nSpire Health GmbH, Oberthulba).

Blood samples

Blood samples were collected from the earlobe in 20µl glass capillaries (EKF-diagnostic GmbH, Magdeburg) after fasting (0 min) and 15, 30, 45, 60, 90, 120, 150, 180, 210 and 240 min after consuming the test breakfast.

Respiratory parameters

Respiratory parameters were measured after fasting (0 min) and 1, 2, 3 and 4 hours after consuming the test breakfast by continuous flow indirect calorimetry. Oxygen uptake (VO_2) and carbon dioxide (VCO_2) were recorded continuously breath by breath and the Respiratory Quotient (RQ) calculated as the ratio of VCO_2 to VO_2.

Record of satiety

Participants recorded their feeling satiety after fasting (0 min) and 20 min and 1, 2, 3 and 4 hours after eating. The feeling was rated using a scale with 0 = no hunger, 2 = slight hunger, 4 = moderate hunger, 6 = strong hunger, 8 = very strong hunger, 10 = strongest imaginable hunger [8].

Statistical analyses

For each participant, complete datasets were available in Microsoft® Excel XP spreadsheets. The results are expressed as means ± standard deviations for all parameters. Incremental Areas Under the Curve (IAUCs) were established for the parameters tested for each subject. The IAUC was defined as the difference between the integrated area under the curve of the postprandial response and the rectangular area determined by the associated fasting value. Thereby, positive and negative areas were included. For satiety, the sum of postprandial satiety scale values (Σ20 240 min) instead of IAUCs was calculated. Each of the four test breakfasts was compared with the control (water). In addition, the variance between diets in terms of the three main nutrients (Carbohydrate, Fat and Protein) was analyzed. All statistical significances were calculated using a combined test (Friedman- and Wilcoxon-Test) with Bonferroni-Holm adjustment for multiple comparisons [9]. Statistical significance was defined as $p < 0.05$. All analyses were performed using SPSS 18.02.

Results

The satiety

Reported feeling of satiety significantly increased following

all breakfast types, with the exception of the (water) control. After correcting for multiple comparisons, all breakfast variations initiated significant changes in satiety or, in the case of the control, in hunger feeling (Table 4). Compared with the control breakfast, satiety feeling 20 min postprandially was significantly enhanced; reported satiety slowly decreased through the course of the testing morning. Participants reported no appreciable differences between the four breakfasts in satiety at the end of the test period (240 min postprandially). The sum of the satiety scale values (Σ20-240 min) (Table 4), followed the order P > CH = N > Fat. The control (water) meal induced twice the feeling of hunger compared to the test breakfasts. Comparing the sum of satiety scale values for the three main nutrients, significant differences in satiety feeling was identified only without correcting for multiple comparisons: the Protein-rich breakfast variant caused a significantly higher satiety feeling compared with the Carbohydrate and Fat-rich breakfasts.

Blood glucose

All breakfast variations except for the control induced a significant postprandial blood glucose peak ($p \leq 0.05$). However, after correction for multiple comparisons, these increases compared to the control were no longer significant. At the postprandial peak at 30 min when the absolute values reached their maximum, the Carbohydrate-rich breakfast induced a 56% increase (the largest) and the Protein-rich breakfast induced a 23% increase (the smallest) in blood glucose compared to the control (Table 5). IAUCs (Figure 1) showed the following order: CH > N > Fat ≈ P. Comparing the IAUCs of the three main nutrients (Carbohydrate, Fat and Protein), the glucose increase after the Carbohydrate-rich breakfast significantly differed from the IAUCs of the Fat and the Protein-rich breakfast variants.

Blood lactate

All breakfast variations except for the control resulted in a significant lactate peak ($p \leq 0.05$). However, after correction for multiple comparisons, only the lactate increases following the Carbohydrate and the Protein-rich breakfasts remained significant (Table 5). The highest absolute lactate values were achieved after 45-60 min. In contrast to blood glucose, the lactate concentration fell below the associated fasting lactate value at the end of the tests. For the postprandial maximal absolute lactate value, the Carbohydrate-rich test breakfast induced a 184% increase (the largest) in blood lactate level, whereas the Fat-rich breakfast resulted in the smallest increase. IAUCs (Figure 1) were in the following order: CH > N ≈ P > Fat.

VO_2

Compared with the water control, postprandial VO_2 significantly increased following all breakfast types. After correction for multiple comparisons, all breakfast types resulted

Table 1: Means ± SD of the characteristics of the subjects (n=10) enrolled.

	Age [y]	**Weight** [kg]	**Height** [cm]	**BMI** [kg/m^2]	**Fat mass** [%]	**VO2$_{max}$** [ml/kg/min]
Mean ± SD (n=10)	25.6 ± 4.4	78.4 ± 5.1	184.0 ± 6.6	23.2 ± 0.9	17.6 ± 3.0	55.9 ± 4.1

Table 2: Energy composition of the five breakfast variations.

	CH [% of energy]	**Fat [% of energy]**	**P [% of energy]**	**Dietary fiber [g]**	**Energy [kcal]**
CH-rich breakfast	68	23	9	6.4	715
Fat-rich breakfast	26	64	10	6.1	688
P-rich breakfast	33	32	35	6.4	700
Individual normal breakfast (Mean$_{1-10}$)	56	31	13	6.6	700
Water breakfast (control)	0	0	0	0	0

Data were calculated with the nutrition software DGE-PC Professional)

Table 3: Composition and Total Weight [TW] of the five breakfast variations.

	Composition/Ingredients	**TW [g]**
CH-rich breakfast	130 g baguette, 10 g butter, 10 g jam, 10 g nut-nougat-cream (sweet), 150 g yoghurt (3.8%) with fruit preparation, 200 ml orange juice	510
Fat-rich breakfast	65 g croissant (flaky pastry), 30 g pumpernickel, 20 g butter, 20 g cheese, 15 g salami, 15 g salmon (cured), 50 g pepper (pepper), 200 ml water or tea	415
P-rich breakfast	35 g multi-grain bread, 25 g whole-grain bread, 6 g butter, 50 g trout (cured), 10 g honey, 50 g curd cheese (low-fat), 5 g nuts (fresh), 80 g orange (fresh, peeled), 70 g hen´s egg (hard-cooked), 50 g soy-based protein-powder (Almased®) dissolved in 200 ml water	581
Individual normal breakfasts	Not listed Mean$_{1-10}$	507
Water breakfast (control)	200 ml water	200

Table 4: Effects of different breakfast variations on satiety feeling according to time.

Satiety Scale (Mean ± SD) (n=10)							
	0 [min]	**20 [min]**	**60 [min]**	**120 [min]**	**180 [min]**	**240 [min]**	**$\Sigma_{20\text{-}240[min]}$**
CH-rich breakfast	4.8 ± 1.4	0.6^{a} ± 0.7	0.9^{a} ± 1.0	1.8^{a} ± 1.1	2.5^{a} ± 1.3	3.6^{a} ± 1.5	9.32
Fat-rich breakfast	4.6 ± 1.4	1.6^{a} ± 1.3	1.9^{a} ± 1.2	2.2^{a} ± 1.4	2.8^{a} ± 2.0	3.8^{ns} ± 1.8	12.41
P-rich breakfast	4.6 ± 1.8	0.5^{a} ± 0.7	0.4^{a} ± 0.7	1.0^{a} ± 1.0	1.5^{a} ± 1.3	3.1^{a} ± 1.3	6.55
Individual normal breakfasts	4.6 ± 2.0	0.9^{a} ± 1.0	1.0^{a} ± 1.0	1.6^{a} ± 1.5	2.5^{a} ± 1.5	3.3^{ns} ± 1.6	9.28
Water breakfast (control)	3.7 ± 2.1	4.1^{ns} ± 1.8	5.0^{a} ± 1.8	5.3^{a} ± 1.6	5.7^{a} ± 1.3	6.7^{a} ± 1.5	26.79

After determining a fasting value (0 [min]), further measurements were taken after subjects consumed the test breakfasts to determine postprandial satiety feeling over the next four hours. Means and associated Standard Deviations [SD] were calculated from the data of the study subjects (n = 10). Data were registered by a questionnaire using the scale with 0 = no hunger, 2 = slight hunger, 4 = moderate hunger, 6 = strong hunger, 8 = very strong hunger, 10 = strongest imaginable hunger. Significances are corrected for multiple comparisons and denoted via letters: **ns**: non-significant; **a**: $*p \leq 0.05$ vs. the corresponding fasting value

Table 5: Effects of different breakfast variations on blood glucose and blood lactate concentrations over time.

Lactate [mg/dl] (Mean ± SD) (n=10)											
	0 [min]	**15 [min]**	**30 [min]**	**45 [min]**	**60 [min]**	**90 [min]**	**120 [min]**	**150 [min]**	**180 [min]**	**210 [min]**	**240 min]**
CH-rich breakfast	0.89 ± 0.35	1.06^{ns} ± 0.35	1.75^{a} ± 0.34	1.93^{a} ± 0.39	1.68^{a} ± 0.49	1.45^{a} ± 0.43	1.17^{ns} ± 0.31	0.92^{ns} ± 0.21	0.85^{ns} ± 0.14	0.80^{ns} ± 0.17	0.72^{ns} ± 0.12
Fat-rich breakfast	0.85 ± 0.30	0.77^{ns} ± 0.24	0.88^{ns} ± 0.24	0.91^{ns} ± 0.26	0.94^{ns} ± 0.24	0.86^{ns} ± 0.16	0.73^{ns} ± 0.15	0.69^{ns} ± 0.16	0.65^{ns} ± 0.10	0.61^{ns} ± 0.11	0.58^{ns} ± 0.08
P-rich breakfast	0.83 ± 0.22	0.83^{ns} ± 0.26	1.11^{a} ± 0.27	1.21^{ns} ± 0.24	1.20^{ns} ± 0.25	1.01^{ns} ± 0.14	0.91^{ns} ± 0.13	0.78^{ns} ± 0.15	0.77^{ns} ± 0.17	0.72^{ns} ± 0.14	0.62^{ns} ± 0.15
Individ. normal breakfasts	0.91 ± 0.27	0.87^{ns} ± 0.32	1.22^{ns} ± 0.39	1.41^{ns} ± 0.50	1.31^{ns} ± 0.36	1.15^{ns} ± 0.34	0.91^{ns} ± 0.23	0.87^{ns} ± 0.16	0.79^{ns} ± 0.14	0.74^{ns} ± 0.13	0.69^{ns} ± 0.11
Water breakfast (control)	0.82 ± 0.27	0.67^{ns} ± 0.22	0.67^{ns} ± 0.20	0.68^{ns} ± 0.16	0.66^{ns} ± 0.15	0.68^{ns} ± 0.17	0.66^{ns} ± 0.17	0.66^{ns} ± 0.14	0.68^{ns} ± 0.13	0.70^{ns} ± 0.16	0.58^{ns} ± 0.09

Glucose [mg/dl] (Mean ± SD) (n=10)											
	0 [min]	**15 [min]**	**30 [min]**	**45 [min]**	**60 [min]**	**90 [min]**	**120 [min]**	**150 [min]**	**180 [min]**	**210 [min]**	**240 min]**
CH-rich breakfast	73 ± 5	93^{a} ± 12	122^{a} ± 19	105^{a} ± 15	87^{a} ± 13	91^{a} ± 9	88^{a} ± 6	90^{a} ± 7	81^{ns} ± 9	79^{ns} ± 6	76^{ns} ± 7
Fat-rich breakfast	76 ± 5	87^{a} ± 9	101^{a} ± 12	93^{a} ± 11	82^{ns} ± 13	80^{ns} ± 9	81^{ns} ± 6	80^{ns} ± 3	80^{ns} ± 3	79^{ns} ± 4	80^{ns} ± 5
P-rich breakfast	77 ± 6	85^{a} ± 7	96^{a} ± 8	85^{ns} ± 8	79^{ns} ± 8	82^{ns} ± 8	82^{ns} ± 6	85^{ns} ± 7	83^{ns} ± 4	82^{ns} ± 7	82^{ns} ± 6
Individ. normal breakfasts	72 ± 5	85^{a} ± 9	112^{a} ± 19	104^{ns} ± 22	84^{ns} ± 11	85^{ns} ± 9	83^{ns} ± 10	83^{ns} ± 14	81^{ns} ± 10	78^{ns} ± 7	76^{ns} ± 8
Water breakfast (control)	75 ± 7	78^{ns} ± 8	78^{ns} ± 6	78^{ns} ± 6	78^{ns} ± 7	76^{ns} ± 6	77^{ns} ± 7	76^{ns} ± 6	77^{ns} ± 6	75^{ns} ± 6	77^{ns} ± 6

After determining a fasting value (0 [min]), further blood samples were taken after subjects consumed the test breakfasts to determine postprandial values over the next four hours. Means and associated Standard Deviations [SD] were calculated from data of the study subjects (n=10).

in significant augmentations in VO_2 (Table 6). Peak VO_2 values occurred 60-120 min after breakfast and returned to fasting levels 180-240 min postprandially. Only the Protein-rich breakfast sustained a significant rise in VO_2 over the entire 240 min period (Table 6). A mean peak oxygen consumption of 0.35 l/min was achieved following the Carbohydrate and Protein-rich breakfasts. However, the decline was more pronounced in the Carbohydrate-rich breakfast, such that the Protein-rich breakfast induced a slightly higher total VO_2 increase over 4 hours. IAUCs were in the following sequence: P ≈ CH > N > Fat. For the control, the IAUC was close to zero (Figure 2).

Respiratory Quotient (RQ)

Respiratory Quotient (RQ) was also influenced by breakfast

Table 6: Effects of different breakfast variations on oxygen consumption [VO2] and the Respiratory Quotient [RQ] according to time.

VO2 [l/min] (Mean ± SD) (n=10)					
	0 [min]	**60 [min]**	**120 [min]**	**180 [min]**	**240 [min]**
CH-rich breakfast	0.27 ± 0.05	0.35^{a} ± 0.05	0.35^{a} ± 0.06	0.31^{a} ± 0.04	0.29^{ns} ± 0.03
Fat-rich breakfast	0.28 ± 0.04	0.31^{a} ± 0.04	0.31^{a} ± 0.04	0.29^{ns} ± 0.03	0.28^{ns} ± 0.03
P-rich breakfast	0.27 ± 0.03	0.34^{a} ± 0.03	0.35^{a} ± 0.04	0.33^{a} ± 0.03	0.30^{a} ± 0.03
Individual normal breakfasts	0.27 ± 0.04	0.32^{a} ± 0.05	0.32^{a} ± 0.04	0.31^{ns} ± 0.04	0.28^{ns} ± 0.04
Water breakfast (control)	0.28 ± 0.05	0.28^{ns} ± 0.05	0.28^{ns} ± 0.04	0.27^{ns} ± 0.03	0.28^{ns} ± 0.02
RQ (Mean ± SD) (n=10)					
	0 [min]	**60 [min]**	**120 [min]**	**180 [min]**	**240 [min]**
CH-rich breakfast	0.86 ± 0.03	0.93^{a} ± 0.03	0.92^{a} ± 0.03	0.91^{a} ± 0.03	0.86^{ns} ± 0.03
Fat-rich breakfast	0.87 ± 0.03	0.84^{ns} ± 0.04	0.84^{ns} ± 0.04	0.83^{ns} ± 0.05	0.82^{a} ± 0.04
P-rich breakfast	0.85 ± 0.04	0.85^{ns} ± 0.03	0.85^{ns} ± 0.04	0.86^{ns} ± 0.03	0.86^{ns} ± 0.05
Individual normal breakfasts	0.87 ± 0.04	0.90^{ns} ± 0.04	0.90^{ns} ± 0.03	0.88^{ns} ± 0.03	0.88^{ns} ± 0.05
Water breakfast (control)	0.84 ± 0.03	0.85^{ns} ± 0.03	0.83^{ns} ± 0.03	0.83^{ns} ± 0.04	0.82^{ns} ± 0.05

After determining a fasting value (0 [min]), further measurements were taken after subjects consumed the test breakfasts to determine postprandial values over the next four hours. Means and associated Standard Deviations [SD] were calculated from the data of the study subjects (n=10). Parameters were recorded by spiroergometry. Significances are corrected for multiple comparisons and denoted via letters: **ns**: non-significant; **a**: $*p \leq 0.05$ vs. the corresponding fasting value.

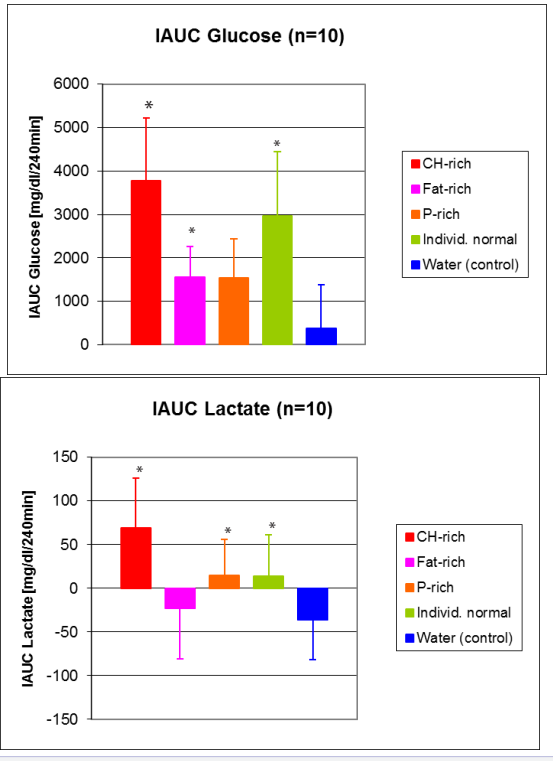

Figure 1: Effects of different breakfast variations on IAUC for blood glucose and lactate. IAUCs were estimated over a time span of four hours after subjects consumed the test breakfast. Illustrated are means and associated standard deviations [SD] calculated from the data of the study subjects (n=10). Significances are corrected for multiple comparisons and denoted with $*p \leq 0.05$ vs. control

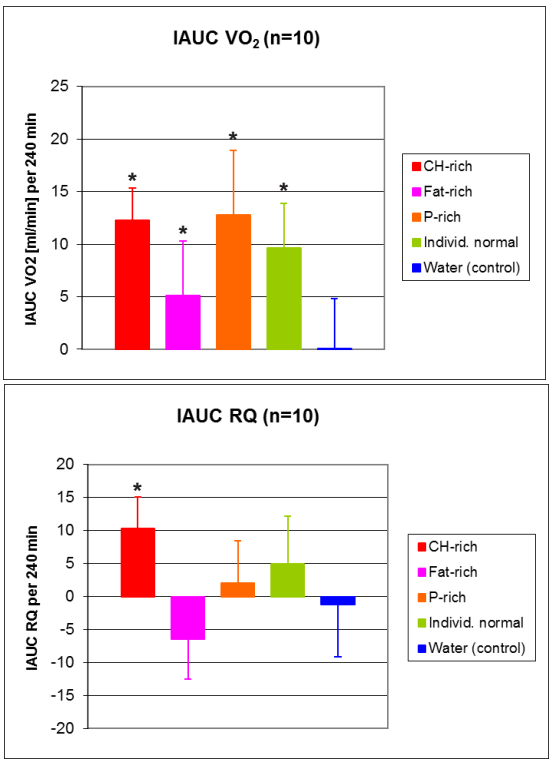

Figure 2: Effects of different breakfast variations on IAUC for oxygen consumption [VO_2] and the Respiratory Quotient [RQ]. IAUCs were estimated over a time span of four hours after subjects consumed the test breakfast. Illustrated are means and associated Standard Deviations [SD] calculated from data of the study subjects (n=10). Significances are corrected for multiple comparisons and denoted with $*p \leq 0.05$ vs. control

type (Table 5). A significant RQ increase was observed after the Carbohydrate-rich and the individual normal breakfasts. In contrast, the Fat-rich breakfast resulted in a significant decline in RQ. The Protein-rich breakfast and the control (water) showed no significant changes from their fasting values. After correction for multiple comparisons, the RQ increase following the Carbohydrate-rich breakfast and the decrease following the Fat-rich breakfast remained significant (Table 5). The Carbohydrate-rich breakfast induced the maximum RQ rise 60 min postprandially (53%) compared to the control. IAUCs show a clear order: CH > N > P > Fat. The IAUC for the control was close to zero. If IAUCs of the main nutrients are compared, the Carbohydrate-rich breakfast induced a significantly greater RQ increase compared with the Fat and Protein-rich breakfasts. Additionally, the RQ decline following the Fat-rich test breakfast significantly differed from the small RQ increase after the Protein-rich test breakfast (Figure 2).

Discussion

This study set out to compare a range of breakfasts rich in either carbohydrate, Fat or Protein on feelings of satiety and a number of metabolic parameters. The intention was to consider whether an optimal level of one particular macronutrient could be proposed as a means of best promoting healthy weight management. The study found that a breakfast high in Protein prolonged satiety promoted an increased in resting metabolic rate and favourably affected postprandial glycaemia compared with the breakfast rich in carbohydrate or Fat.

Several studies have indicated that eating breakfast is a health-promoting behaviour [10-14], even though it may contribute to higher total daily energy intake [15]. In contrast, skipping breakfast is associated with a low frequency of health-promoting behaviours [16,17]. In this study, it could be viewed that the effects of skipping breakfast were imitated in the control breakfast where only plain water was provided. It was found that postprandial values of metabolic and respiratory parameters from the control remained around fasting values; thus, an increase in resting metabolic rate failed to occur. However, at the end of the test day, participants perceived a strong hunger feeling, which could lead to overeating at lunch. In contrast, the four isoenergetic (~700 kcal) breakfast variants yielded clear postprandial responses and macronutrient-dependent effects.

As increased glucose levels promote insulin secretion, inhibit fat oxidation and possibly increase hunger [18,19], an excessive postprandial glucose increase may be unfavourable for healthy weight management [20]. As expected, the high-CH breakfast variants (the Carbohydrate-rich and the individual normal breakfast) led to the greatest increases in blood glucose. The Fat and Protein-rich test breakfasts resulted in increases in glucose levels that were approximately half that of the individuals usual or normal breakfast. The difference may be explained by a higher fructose content in the Carbohydrate-rich breakfast because more lactate is produced when more fructose is consumed [21]. Variation in postprandial energy expenditure might play an important role in the development of overweight. Indeed, several parameters have been found to be predictive for weight gain including a low basal or resting metabolic rate, high fasting and/or postprandial RQ which reflect a low fat oxidation rate and low endurance fitness and low spontaneous physical activity [22-25]. With this study, we attempted to make more precise statements about the effects of different breakfast types on energy metabolism. The results indicated that a higher intake of carbohydrate induced a pronounced increase of VO_2 but also significantly augmented RQ, indicating an inhibition of fat oxidation. Therefore, it could be suggested that a high carbohydrate breakfast has disadvantageous effects on both blood and respiratory parameters, compared with, for example a high Protein breakfast. The findings also suggest that in relation to long-term weight management, the participants' individual choices for their daily breakfast, which on average, amounted to approximately 56% of energy, should be questioned. Following the Fat-rich breakfast, the enhancement of VO_2 was the lowest, and the postprandial fat oxidation was the highest. Nevertheless less than half the amount of fat consumed was oxidized. It is likely that endogenous fat stores would not be affected by the increased fat oxidation but rather are expanded by the residual dietary fat that was not oxidized. From these findings it could be claimed that the high fat intake cannot be balanced without additional energy expenditure through physical activity. Only the Protein-rich test breakfast was able to influence both respiratory parameters in a direction considered favourable for weight management VO_2 increased, RQ was kept constant and postprandial fat oxidation remained at a proportionately high level. For the Protein-rich breakfast, the calculated mean ratio of fat oxidation was 46% instead of the 32.5% after the Carbohydrate-rich breakfast.

The results of previous studies indicated that dietary Protein induces a higher and longer thermic effect compared with either carbohydrate or Fat [26-29]. This response may be a key factor which explains why increased dietary Protein seems to prevent weight gain and/or regain after weight loss [30-36]. The fact that there is no capacity to store Protein, and it thus has to be immediately metabolized, may be one explanation for the macronutrient-dependent differences in the thermic effect. The diet-induced increase in VO_2 between the Protein and the Carbohydrate-rich breakfasts showed minimal differences (Figure 2). However, by multiplying the amount of additional VO_2 with the energy-equivalent for O_2 (rounded to 5 kcal/l O_2), it was calculated that the consumption of both breakfast variants enhanced EE by approximately 63 kcal during the testing morning. This result is consistent with 9% of total energy consumed (700 kcal) but in itself does not explain the higher thermic effect after Protein intake. One possible explanation may be the unequal content of the "main" macronutrient of the particular breakfasts. In this study the carbohydrate content of the Carbohydrate-rich breakfast accounted for 68% of energy, whereas the Protein content of the Protein-rich breakfast accounted for 35% of energy - approximately half as much. Therefore, the "real" thermic effect of Protein is likely underrepresented. Additionally a longer lasting thermic effect, up to more than six hours after Protein intake could also explain the differences as the increase of VO_2 after the Protein-rich breakfast may be underestimated due to a measurement period of only four hours [27,37]. Possibly

any differences were too small to define a clear macronutrient-dependent order for VO_2. However, the results of this study provide evidence for an order for RQ and substrate oxidation: the higher the carbohydrate content and/or the lower the fat content of the breakfast, the higher the postprandial RQ and thus, carbohydrate oxidation, and the lower the postprandial fat oxidation.

Macronutrients are also responsible for satiety. Carbohydrates and especially Protein have greater satiety-enhancing potential than fat [27,38-41] and the results of this study support this observation. However, the macronutrient-dependent response on satiety become weaker across the measurement period, so that finally satiety scale values noted 240 min postprandial are all within a similar range (control excluded). Further investigations would be required to determine the exact mechanism(s) by which Protein and carbohydrates enhance satiety. However, there is evidence in the literature which indicates that macronutrients that induce a high thermic effect may lead to an increased suppression of hunger [33,42,43].

Moreover, these findings agree with the suggestion given by Jéquier [40] that the small, fat-induced influence on satiety may be explained by the fact that appetite regulation signals, such as Cholecystokinin [CCK], are too weak or occur too late to avoid excessive food intake. Supporting Jéquier´s thesis, it was observed that that the Fat-rich breakfast initiated the lowest, and a temporally delayed, satiety feeling, even though all test breakfasts were isoenergetic (control excluded). With regard to healthy weight management, this would be an inappropriate effect.

It was also investigated if the total weight of the meal consumed impacted satiety, as the volume of the stomach content should activate satiety signals. We found that, the higher the total weight (Table 3) of the breakfast variation, the higher the sum of the postprandial satiety scale values (Table 6). Nevertheless, at the end of the morning test (240 min postprandial), no significant differences in satiety scale values were observed. It is possible that there must be further satiety-influencing factors. Finally, to explore and understand the effects of a Protein-rich meal to reduce in-between meal snaking to reduce energy intake or portion size at lunch and influence macronutrient choice in following meals further research is required.

One of the limitations of this study was that external factors, such as the physical and mental states of the subjects or their recent dietary intake may have affected the results. In addition, to offer an acceptable breakfast suitable for daily use, the percentage of Protein energy of the Protein-rich breakfast was lower than the percentages of carbohydrate and fat energy of the Carbohydrate and Fat-rich breakfasts, respectively. The "real" Protein-induced effects were underestimated. Another difficulty in interpreting these results is that macronutrients´ source and type have not been taken into account for the preparation of the Carbohydrate, Fat and Protein-rich breakfasts. Furthermore, all postprandial parameters were only followed up over four hours of test meal. The diet-induced effects over the entire day were not assessed and total daily energy intake and macronutrient composition of later meals were not recorded. To improve knowledge of the optimal timing of a higher Protein intake, not just the diet-induced effects after breakfast but also after later meals (lunch and dinner) with an increased Protein-load should be investigated. Moreover, women were not included in the study as we aimed to reduce the effect of hormonal variability, which could have influenced the measured parameters. Finally, all subjects tested were young, fit and of a healthy weight. In view of the fact that changes in age, physical fitness and weight are associated with alterations in metabolic and respiratory parameters, participants who are overweight or obese should be examined in future studies.

Conclusions

The results of this short-term study suggest that postprandial differences in glucose regulation, energy metabolism and satiety feeling may appear minor when comparing the macronutrient composition of breakfasts. However, the daily contribution of the Protein-initiated combined effects of a reduced glycemic response, an increased postprandial VO_2 with a proportionately higher fat oxidation and stronger satiety might be advantageous for weight regulation in healthy weight men. Other studies suggest that the same positive effects could be expected in overweight and obese people. Nevertheless there is still a need for further and long-term studies, to clarify the role of the amount and quality of Protein eaten on a continuing basis and the timing of Protein intake for the prevention and/or treatment of overweight and obesity.

Competing Interests and Disclosures

Research related of this study was funded by the Almased GmbH, Bienenbüttel, Germany, and A. Berg has written "The Almased Wellness Concept" outlining the effects of a soy-enriched diet in health and disease.

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