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Postabsorptive respiratory quotient and food quotient—an analysis in lean and obese men and women

AHC Goris[1]* and KR Westerterp[1]

[1]*Department of Human Biology, Maastricht University, Maastricht, The Netherlands*

Objective: Macronutrient intake is difficult to measure under free-living conditions, because of errors in the reporting of food intake. The aim of the current study was to assess whether postabsorptive respiratory quotient (RQ) is indicative for the food quotient (FQ), with other factors, such as body composition and energy balance, taken into account.

Subjects: Thirty lean subjects (age 31 $\pm$ 9 y, body mass index (BMI) 22.0 $\pm$ 2.1 kg/m^2) and 20 obese subjects (age 48 $\pm$ 12 y, BMI 33.3 $\pm$ 4.4 kg/m^2) participated in the study.

Design: Body mass changes were determined over a 7 day period before the measurement of postabsorptive RQ and in this period subjects reported their total food intake in a dietary record. A subgroup of 12 lean subjects was supplied with their total food intake in this period (twice with different diets). Food quotients were calculated from the valid food records (< 10% underrecording and undereating). Body composition was estimated using the three-compartment model of Siri.

Results: Postabsorptive RQ was not related to FQ ($n = 31$, $r = -0.24$, $P = 0.2$) and no difference was observed between the two diet periods ($n = 12$ paired t-test, $P = 0.9$). Postabsorptive RQ was related to the change in body mass ($r = 0.57$, $P = 0.0001$), but not to BMI, fat mass or fat-free mass.

Conclusions: In the present study, the energy balance over the days prior to the measurement was the most important factor influencing postabsorptive RQ. Postabsorptive RQ was not a reliable indicator for habitual FQ even when corrected for energy balance and body composition.

Descriptors: postabsorptive RQ; FQ; energy balance; body composition

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Introduction

Postabsorptive respiratory quotient (RQ) is often related to measures of body composition (Astrup *et al*, 1994; Schutz *et al*, 1992; Nagy *et al*, 1996) and/or used as a predictor for future weight gain or weight loss (Seidell *et al*, 1992; Schutz, 1995). In some studies subjects with a higher fat mass (FM) were found to have a lower postabsorptive RQ (Astrup *et al*, 1994; Schutz *et al*, 1992). A large fat mass, as a consequence of a positive energy balance, might increase fasting free fatty acid levels and the rate of fat turnover until fat oxidation is commensurate with dietary fat intake (Astrup & Raben 1992; Astrup *et al*, 1994; Schutz *et al*, 1992). Other studies found a negative relation between postabsorptive RQ and fat-free mass (FFM) (Nagy *et al*, 1996; Toth *et al*, 1999). The FFM is a more metabolically active compartment of the body than fat mass and is therefore responsible for the fat oxidation. The interindividual variability in postabsorptive RQ seems to be only partly explained by differences in the amounts of FM and/or FFM. The role of the macronutrient ratio of the food intake, ie the food quotient (FQ), is also thought to influence postabsorptive RQ (McNeill *et al*, 1988). Normally, subjects who are in energy balance are also in substrate balance; the RQ measured over a 24 h period is equal to FQ (Flatt, 1993). Whether or not postabsorptive RQ is also related to FQ is not clear. The FQ is difficult to measure, because of errors in the reporting of food intake. In a previous study with obese men we found a selective underreporting of fat intake with the use of a 7 day dietary record (Goris *et al*, 2000). Obviously, other methods to assess habitual macronutrient intake are needed for nutrition research.

The aim of this study was to assess whether postabsorptive RQ is indicative for FQ, with other factors, such as body composition and energy balance, taken into account. We hypothesized that postabsorptive RQ is related to FQ, and that postabsorptive RQ will change when FQ changes. Measurements were done in lean subjects and obese subjects (before and at the end of a weight loss intervention). The energy balance was measured over a one week interval and in the obese subjects also over a 10 week weight loss intervention interval.

Methods

Design

For a first study, 30 lean subjects (BMI < 27 kg/m^2), a group of dieticians and a group of students were recruited from the university and the university hospital in Maastricht. For a second study twenty obese subjects (BMI $\geq$ 27 kg/m^2) were recruited from a weight loss intervention of the local home nursing association in Maastricht. They were studied before the start and at the

*Correspondence: AHC Goris, Department of Human Biology, Maastricht University, PO Box 616, 6200 MD Maastricht, The Netherlands.
E-mail: a.goris@hb.unimaas.nl
Guarantor: AHC Goris.
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end of the intervention. The weight loss intervention consisted of weekly group meetings under supervision of a dietitian who gave information about nutrition and who weighed the subjects.

For all subjects, body mass changes were determined over a 7 day period before the measurement of postabsorptive RQ and in this period subjects reported their total food intake in a dietary record. A subgroup of 12 lean subjects followed the protocol twice and received two different diets from the university. The formation of this subgroup made it possible to study the effect of a change in diet on the postabsorptive RQ. Physical activity was measured to control for differences in physical activity which might influence the RQ measurement. The protocol was approved by the university ethics committee.

Food intake

A 7 day weighed food record was used to measure habitual macronutrient intake. The reporting of food intake was checked for underrecording and undereating (Goris & Westerterp, 1999). Recording was checked with the water balance technique, as described previously (Goris & Westerterp, 1999; Goris *et al*, 2000). Briefly, healthy subjects are in water balance and water intake matches water loss. A water intake, corrected for metabolic water, lower than water loss indicates underrecording of water intake. The recording of water intake appeared to be representative for total food recording, thus a reported water intake below water loss indicates underrecording of food intake. Water loss was measured with the deuterium elimination method (Fjeld *et al*, 1988). Subjects drank a deuterium (^2H_2O) dilution (70 g water with an enrichment of 5 atom% excess ^2H) after voiding (baseline urine sample) the evening before the start of the recording week. Elimination was calculated from two urine samples directly after dosing (at day 1 in the morning and evening) and two samples at the end of the observation period (day 7 in the evening, day 8 in the morning). Deuterium content was measured in urine samples with an isotope ratio mass spectrometer (Aqua Sira, VG Isogas, Middlewich, Cheshire, UK; Westerterp *et al*, 1996). Water loss was calculated from ^2H elimination with the equation of Fjeld *et al* (1988), as described previously (Westerterp *et al*, 1992). Undereating was checked by comparing the body mass change over the recording week with the body mass change over a non-recording week. A significantly higher body mass loss over the recording week indicates undereating (Goris & Westerterp, 1999).

Food quotients were calculated from the valid food records (50% of the food records were judged valid, ie less than 10% underrecording and undereating). The data of the food records were used to calculate intakes of fat, carbohydrate and protein with a computer program based on food tables (Becel Nutrition Program, 1988, Nederlandse Unilever Bedrijven BV, Rotterdam, The Netherlands). The food quotient was then calculated using the following equations: O_2 consumption (l/day) $= (0.966 \times$ protein intake) $+ (2.019 \times$ fat intake) $+ (0.829 \times$ carbohydrate intake), and CO_2 production (l/day) $= (0.774 \times$ protein intake) $+ (1.427 \times$ fat intake) $+ (0.829 \times$ carbohydrate intake), where the intake of protein, fat and carbohydrate is expressed in grams per day; $FQ = VCO_2/VO_2$ (Jequier *et al*, 1987).

A subgroup of 12 lean subjects received over two 4 day intervals a diet with a fixed macronutrient composition (each interval a diet with a different composition). One diet according to the habitual macronutrient composition, as estimated with a dietary history, and one diet with more/less fat than the habitual diet ($\pm$ 0.04 of habitual FQ). Subjects could choose the food items and meals they preferred for the next four days, from a list with a fixed FQ. Foods and drinks were given *ad libitum*. The interval between the two diets was at least four days.

Substrate oxidation

Postabsorptive RQ (ml CO_2/ml O_2) was measured by means of an open circuit ventilated hood system while subjects were lying in the supine position. Gas analyses were performed by a paramagnetic oxygen analyzer (Servomex type 500A, Crowborough Sussex, UK) and an infrared carbon dioxide analyzer (Servomex type 500A), similar to the analysis system described by Schoffelen *et al* (1997). Measurements were performed in the morning in a fasting state for about 45 min. The last 30 min were used to calculate postabsorptive RQ. Subjects slept the night before the measurement at the university ($n = 22$) or else they were asked to come by car or public transport to the university ($n = 28$) and to perform as little activity as possible. They lay down for 15 min before the start of the measurements.

Body composition

Subjects were weighed (in underwear) in the morning, before any beverage or food consumption and after voiding, on a digital balance accurate to 0.01 kg (Sauter, type E1200, Albstadt 1, Ebingen, Germany). Body composition was estimated from the three-compartment model of Siri. Body density was determined by underwater weighing with simultaneous assessment of residual lung volume with the helium dilution technique using a spirometer (Volugraph 2000, Mijnhardt, The Netherlands). Total body water was measured by deuterium dilution following the Maastricht protocol (Westerterp *et al*, 1995). The evening prior to the underwater weighing subjects drank a deuterium dilution (70 g water with an enrichment of 5 atom% excess ^2H) after voiding. Deuterium enrichment was measured in urine from the second voiding of the following morning. For comparison between individuals, corrections for differences in body height were made by calculating the fat mass index (FMI $=$ kg FM/m^2) and fat-free mass index (FFMI $=$ kg FFM/m^2).

Physical activity

Physical activity was assessed with a CSA accelerometer (Computer Science and Applications Inc., Shalimar, USA), which subjects wore during waking hours in a belt at the back of the waist (Melanson & Freedson 1995). The registered counts/min were used as an objective measure for the individual's physical activity level.

Statistics

Mean values and standard deviations (s.d.) were calculated for the total group of 50 subjects and for the obese and lean subjects separately. For the subjects with a reliable FQ (ie subjects with a valid food record and the subjects who received their diet from the university), simple regression analysis was done for postabsorptive RQ and FQ. For the subjects who were supplied with food only the 'habitual' FQ (ie the FQ of the supplemented diet according to the macronutrient composition of the dietary history)

+corresponding RQ was used for this analysis. The measurements of postabsorptive RQ after the two different diets were compared with a paired *t*-test. In the obese subjects the relationship of a change in body mass after 10 weeks and postabsorptive RQ was tested with a simple regression analysis. The influence of body mass index (BMI), FMI and FFMI on postabsorptive RQ was analyzed with a simple regression.

Results

Body composition
Subjects' characteristics are shown in Table 1. The mean change in body mass over the 5–7 days before the RQ measurement was, for the lean and obese subjects respectively, − 0.38 (s.d. 0.77) kg, and − 0.27 (s.d. 1.09) (one factor ANOVA $P=0.693$). The body mass change of the lean subjects was significantly different from zero (one group *t*-test, $P=0.012$). There was no difference in mean body mass change between the two diet periods in the subgroup of 12 subjects (paired *t*-test, $P=0.703$).

The obese subjects lost on average 5.2 (s.d. 3.3, range 0.58–10.0) kg after 10 weeks of participation in a weight loss program.

Physical activity
The mean physical activity was 82.6 (s.d. 32.9) counts/min for the lean subjects and 66.5 (s.d. 18.9) counts/min for the obese subjects (one-factor ANOVA $P=0.055$). Physical activity was not related to postabsorptive RQ. For the subjects who were supplied with food, there were no differences in physical activity (counts per min) between the two periods with different diets.

Substrate oxidation
Figure 1 shows RQ plotted against FQ for the subjects with a valid food record and the subjects who were supplied with food ($r=-0.236$, $P=0.2$). RQ was significantly lower than FQ (paired *t*-test, $P=0.0003$) and had also a wider range than FQ. The FQ range of 0.82–0.88 corresponded with an energy percentage fat in the diet of 27–44 and an energy percentage carbohydrate in the diet of 40–64. The postabsorptive RQ was related to the body mass change over the week before the measurement ($r=0.42$, $P=0.024$ for the subjects with a valid food record and $r=0.57$, $P=0.0001$ for all subjects, Figure 2). A high RQ was observed in subjects with a weight gain and vice versa. FQ was also not significant related to postabsorptive RQ in a multiple regression analysis on RQ, with body mass change and FQ as independent factors. Figure 3 shows the postabsorptive RQ measured after a low-fat diet and after a high-fat diet for the 12 lean subjects who were supplied with their food for 4 days. Postabsorptive RQ did not differ between the two periods (paired *t*-test, $P=0.88$) and was not influenced by FQ (simple regression analysis on low FQ, $r^2=0.2$, $P=0.15$; and on high FQ, $r^2=0.11$, $P=0.3$).

Table 1 Age, body mass, fat mass, fat free mass, body mass index, fat mass index and fat-free mass index for obese and lean subjects, mean values, standard deviations and ranges

	Lean subjects (n = 30)	*Obese subjects (n = 20)*	*Total group (n = 50)*
Male/female	4/26	5/15	9/41
Age	31 ± 9	48 ± 12*	38 ± 13
	(21–60)	(25–63)	
Body mass (kg)	62.6 ± 9.0	92.8 ± 13.8*	75.2 ± 18.7
	(47.1–92.7)	(68.0–115.5)	
Fat mass (kg)	16.8 ± 4.9	40.9 ± 10.1*	26.8 ± 14.1
	(8.0–26.7)	(28.3–60.7)	
Fat-free mass (kg)	45.8 ± 7.5	52.0 ± 8.6*	48.4 ± 8.4
	(35.6–68.4)	(36.0–68.9)	
Body mass index (kg/m^2)	22.0 ± 2.1	33.3 ± 4.4*	26.5 ± 6.4
	(18.1–26.1)	(27.0–43.9)	
Fat mass index (kg/m^2)	5.9 ± 1.7	14.6 ± 3.9*	9.6 ± 5.2
	(2.5–9.5)	(9.1–23.0)	
Fat-free mass index (kg/m^2)	16.0 ± 1.4	18.5 ± 1.8*	17.0 ± 2.0
	(13.3–19.0)	(15.5–21.7)	

* $P<0.05$.

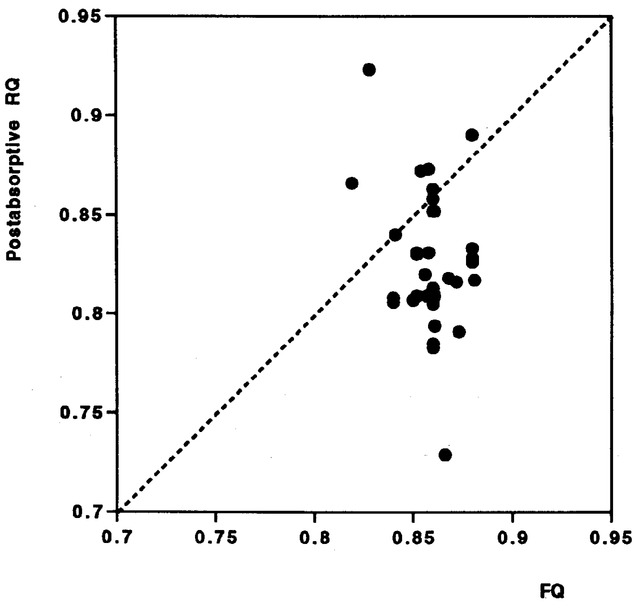

Figure 1 Postabsorptive respiratory quotient (RQ) in relation to the food quotient (FQ) of 31 subjects, with the line of identity plotted (simple regression analysis: $r=-0.24$, $P=0.2$).

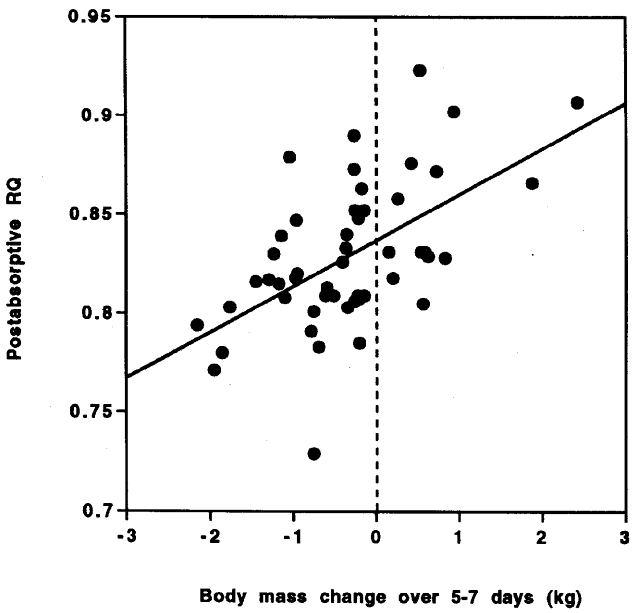

Figure 2 Postabsorptive respiratory quotient (RQ) as a function of the body mass change (ΔBM) in 50 subjects (linear regression line: postabsorptive RQ = 0.023* ΔBM + 0.837: $r=0.57$, $P=0.0001$).

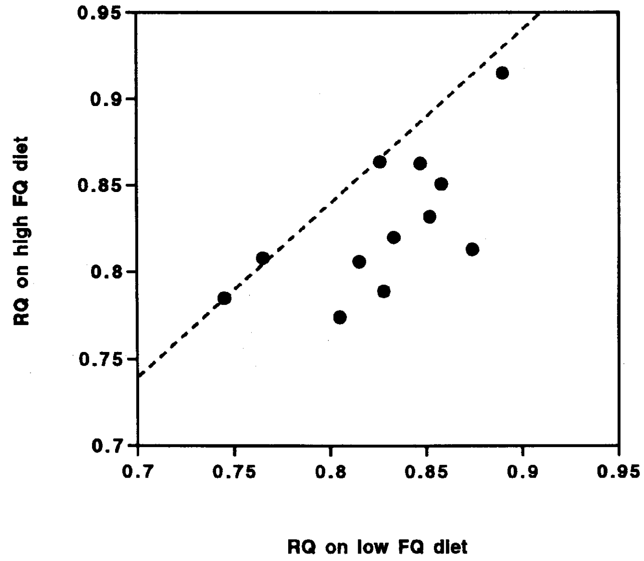

Figure 3 Postabsorptive respiratory quotient (RQ) of 12 subjects after a diet with a low food quotient (FQ) and after a diet with a high food quotient (dashed line is difference in FQ of 0.04 of the diets).

The results of simple regression analysis of BMI, FMI and FFMI on postabsorptive RQ are shown in Table 2. RQ was not related to BMI, FMI or FFMI in the whole group. In the obese group RQ was significantly related to BMI and FMI.

The body mass change over the 10 weeks weight loss intervention in the obese subjects did not change the postabsorptive RQ significantly (0.832 (s.d. 0.039) before *vs* 0.818 (s.d. 0.035) after). The postabsorptive RQ at the end of the weight loss intervention was a function of the change in body mass over the week before the measurement (simple regression analysis $r = 0.53$, $P = 0.02$) and of the change in body mass over the 10 weeks intervention ($r = 0.47$, $P = 0.048$). In a stepwise regression analysis, only the change in body mass over the week before the measurement was related to postabsorptive RQ.

Discussion

In the present study, postabsorptive RQ was not related to (estimated) FQ. Even a change in diet did not affect postabsorptive RQ. Postabsorptive RQ was only related to the change in body mass over the week before the measurement. Subjects with a positive energy balance (a weight gain) had a higher postabsorptive RQ than subjects who were in negative energy balance (a weight loss). McNeill *et al* (1988) found in their study a difference in fasting RQ after two different diets in 11 subjects. The fasting RQ was 0.82 after the diet with a FQ of 0.85 and 0.85 after the diet with a FQ of 0.88 (McNeill *et al*, 1988). Figure 3 shows that in the current study only five out of the 12 subjects had a higher postabsorptive RQ after the diet with the high FQ than after the diet with the low FQ. A measurement of a fasting RQ is not sufficient to get an indication of someone's habitual FQ. One reason could be that fasting RQ represents only a short period of the day. The measurement of a 24 h RQ is probably more indicative for habitual FQ (Hill *et al*, 1991; Astrup, 1993). Verboeket-van de Venne *et al* observed a relation between 24 h RQ and FQ as measured with a 3 day dietary record before the measurement of 24 h RQ (Verboeket-van de Venne *et al*, 1996). However a 24 h RQ measurement in a respiration chamber is not a very practical method to get an indication of someone's habitual FQ. A second reason for the lack of a relation between postabsorptive RQ and FQ might be the time of measurement. Lean and James (1988) observed diurnal changes in postabsorptive RQ with a minimum during the early night (0.00–3.00 h) and a rise in RQ during the later part of the night. The systematic change of RQ was more marked in the obese and post-obese subjects (Lean & James 1988). All subjects in the current study were measured after an overnight fast between 7.00 and 9.00 o'clock in the morning. Thus possible differences in fasting RQ between lean and obese subjects might not have been discovered. Twenty-eight out of the 50 subjects (both obese and lean subjects) had to come by car or public transport to the university, which might have influenced the measurement of postabsorptive RQ. However, all subjects were within 30 min drive from the university.

The relation between postabsorptive RQ and FQ was analyzed in a group of subjects of whom the FQ was calculated from a food record and in a group of subjects of whom the FQ was calculated from the provided diet. FQ was only calculated from the food records if the underrecording and undereating was less than 10%. A correct reported energy intake gives no guarantee for correct reported macronutrient intakes, but a selective underrecording of, for example fat intake has then to be accompanied by an overrecording of carbohydrate/protein intake. This is not very likely. Besides, the result of the analysis of postabsorptive RQ and FQ was not different for the total group and for the 12 subjects who received their diet from the lab.

The relation of postabsorptive RQ with FM, FFM and BMI as reported before could not be confirmed (Schutz *et al*, 1992; Astrup *et al*, 1994; Nagy *et al*, 1996; Toth *et al*, 1999). Only in the subgroup of obese subjects did we observe a negative relation of FMI and BMI with postabsorptive RQ.

The body mass change over the week before the measurement influenced postabsorptive RQ more than the body mass change over the past 10 weeks of the weight loss intervention for the obese subjects. The weight loss over a 10 week interval is probably not constant, which might explain the greater influence of the body mass change over the week prior to the measurement on postabsorptive RQ. The obese subjects who lost weight before the first measurement of postabsorptive RQ were also the subjects who lost most weight during the weight loss intervention. They

Table 2 Simple regression analysis of postabsorptive RQ on BMI, FMI and FFMI

	Lean subjects (n = 30)	*Obese subjects (n = 20)*	*Total group*
BMI (kg/m^2)	$r = -0.29$, $P = 0.12$	$r = -0.54$, $P = 0.01$	$r = -0.04$, $P = 0.77$
FMI (kg/m^2)	$r = -0.03$, $P = 0.88$	$r = -0.53$, $P = 0.02$	$r = -0.03$, $P = 0.85$
FFMI (kg/m^2)	$r = -0.26$, $P = 0.18$	$r = -0.16$, $P = 0.49$	$r = -0.04$, $P = 0.80$

started with a lower postabsorptive RQ (because of the negative energy balance) than the subjects who did not lose weight before the first measurement and maintained this lower RQ until the end of the intervention. This might explain why no difference was observed in postabsorptive RQ between the start and end of the weight loss intervention.

The body mass change prior to the measurement of RQ was probably due to the recording of the food intake. The recording of food intake for a week is known to change eating habits (Goris & Westerterp 1999; Goris *et al*, 2000). It is unlikely that the change in body mass was due to changes in the degree of hydration of the body or differences in gut content in this study. The body mass was always measured at the same time for each subject before any beverage or food consumption and after voiding. Most people have a regular defecation pattern and the gut content will not much differ between the two measurements. The measurement of body mass changes is necessary in the interpretation of postabsorptive RQ, even if there is no significant change in body mass on a group level. The wide range in postabsorptive RQ found in this study was related to the body mass change, which ranged from -2.2 to $+2.4$ kg/week.

In conclusion, in the present study the energy balance over the days prior to the measurement was the most important factor influencing postabsorptive RQ. Postabsorptive RQ is not a reliable indicator for habitual FQ even when corrected for energy balance and body composition.

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