Inaccuracies in food and physical activity diaries of obese subjects: complementary evidence from doubly labeled water and co-twin assessments.

International Journal of Obesity (2010) 34, 437–445

0307-0565/10 $32.00
www.nature.com/ijo

ORIGINAL ARTICLE

Inaccuracies in food and physical activity diaries of obese subjects: complementary evidence from doubly labeled water and co-twin assessments

KH Pietiläinen[1,2,3], M Korkeila[1,2], LH Bogl[2], KR Westerterp[4], H Yki-Järvinen[3], J Kaprio[2,5,6] and A Rissanen[1]

[1]*Department of Psychiatry, Obesity Research Unit, Helsinki University Central Hospital, Helsinki, Finland;* [2]*Department of Public Health, The Finnish Twin Cohort Study, University of Helsinki, Helsinki, Finland;* [3]*Division of Diabetes, Department of Medicine, Helsinki University Central Hospital, Helsinki, Finland;* [4]*Department of Human Biology, University of Maastricht, Maastricht, The Netherlands;* [5]*Department of Mental Health and Substance Abuse Services, National Institute for Health and Welfare, Helsinki, Finland and* [6]*Institute for Molecular Medicine FIMM, Helsinki, Finland*

Objective: To study whether eating or physical-activity (PA) habits differ between obese and non-obese monozygotic (MZ) co-twins independent of genetic effects.
Methods: Rare MZ pairs discordant for obesity ($n=14$, body mass index difference $5.2\pm1.8\,kg\,m^{-2}$) and weight-concordant control pairs ($n=10$, $1.0\pm0.7\,kg\,m^{-2}$), identified through a population-based registry of 24–28-year-old twins ($n=658$ MZ pairs), completed 3-day food and PA diaries and eating behavior questionnaires. Each twin was asked to compare his/her own eating and PA patterns with the co-twin's behavior by structured questionnaires. Accuracy of energy intake was validated by doubly labeled water.
Results: Non-obese co-twins consistently reported that their obese twin siblings ate more food overall, consumed less healthy foods and exercised less than the non-obese co-twins do. However, no differences in energy intake (9.6 ± 1.0 MJ per day vs 9.8 ± 1.1 MJ per day, respectively) in the food diaries or in the mean PA level (1.74 ± 0.02 vs 1.79 ± 0.04, respectively) in the PA diaries were found between obese and non-obese co-twins. A considerable underreporting of energy intake (3.2 ± 1.1 MJ per day, $P=0.036$) and overreporting of PA (1.8 ± 0.8 MJ per day, $P=0.049$) was observed in the obese, but not in the non-obese co-twins.
Conclusions: On the basis of rare MZ twin pairs discordant for obesity, the co-twin assessments confirmed substantial differences in eating and PA behavior between obese and non-obese persons. These may be overlooked in population studies using food and PA diaries because of considerable misreporting by the obese.
International Journal of Obesity (2010) **34,** 437–445; doi:10.1038/ijo.2009.251; published online 15 December 2009

Keywords: twin studies; underreporting; physical-activity diaries; food diaries

Introduction

Energy dense, nutrient-poor foods with high levels of sugar and saturated fats and reduced physical activity (PA) have been associated with the current obesity epidemic.[1] However, data documenting that the intake of food and high-fat foods in particular would be larger in obese subjects than in non-obese subjects have been conflicting.[2–12] Some studies have reported that obese as compared with lean subjects do not markedly differ in energy intake[10] or eating patterns,[2,5,11] whereas others have found that obese young adults[12] and adults[7] consume even fewer calories than their lean counterparts.

Differential reporting of food intake between lean and obese subjects remains a special concern in studies examining the association between self-reported food intake and obesity. Obese subjects may underreport their food intake more than normal weight subjects and may both eat less and underrecord more during any study period than non-obese subjects.[13,14] The most likely explanation for the underreporting of food intake is related to the social desirability bias, so that foods of low social desirability, such as those

Correspondence: Dr KH Pietiläinen, Department of Psychiatry, Obesity Research Unit, Biomedicum Helsinki, PO Box 700, Helsinki University Central Hospital, Helsinki FIN-00029, Finland.
E-mail: kirsi.pietilainen@helsinki.fi
Received 2 June 2009; revised 15 September 2009; accepted 5 October 2009; published online 15 December 2009

rich in fat and simple carbohydrates, are underreported to a larger extent than those high in protein.[13,15] The failure to establish a firm correlation between energy intake and obesity may also arise from the fact that obese subjects do not need more energy than non-obese subjects if their energy expenditure (that is PA) is low. In addition, the correlation may be weakened by genetic differences in the susceptibility to gain weight with similar levels of energy intake. Thus, for many reasons, it has proven difficult to show differences in energy intake and eating patterns between obese and lean individuals.

Monozygotic (MZ) twin pairs discordant for obesity offer a unique opportunity to study independent associations of dietary intake and eating behavior with obesity controlling for genetic effects. In earlier studies on adult weight-discordant MZ twins from the older Finnish Twin Cohort, both members of the middle-aged twin pairs agreed that obese co-twins were eating more both in past and at present and had a stronger preference for fatty foods than their lean co-twins.[16,17]

The aim of this study is to investigate which eating and PA behaviors are associated with obesity in young adult MZ twins. Twin pairs highly discordant for obesity and weight-concordant control pairs were asked to keep 3-day food and PA diaries and compare their own eating and PA behavior with their co-twin's behavior by structured questionnaire. Further, in discordant pairs, the energy intake from food diaries was validated by using the doubly labeled water (DLW) technique, which is considered the gold standard for measuring energy expenditure under free-living conditions.[18,19]

Materials and methods

Subject characteristics

The study participants were recruited from the FinnTwin16 cohort, which is a population-based, longitudinal study of five consecutive birth cohorts of Finnish twins born between 1975 and 1979.[20] Eighteen healthy obesity-discordant MZ pairs above the 95th percentile of body mass index (BMI) differences in which one co-twin was obese (BMI $\sim 30\,kg\,m^{-2}$) and the other one non-obese (BMI $\sim 25\,kg\,m^{-2}$), with no significant height differences (<4 cm), were found among all MZ twin pairs ($n=658$ pairs). Fourteen of these pairs (eight male and six female pairs) were willing to participate in this study.[21–25] We also studied 10 weight-concordant MZ pairs matched for age, gender and socioeconomic status.[21–25]

All pairs were Caucasian and their mean age was 26 (range 23–28) years. The absence of weight cycling within the past 3 months, concomitant diseases, regular medication (except contraceptives), anemia, hypothyreosis, psychiatric diseases and eating disorders were ascertained by clinical examination and structured interviews. The zygosity was confirmed by genotyping of 10 informative genetic markers.[26] All pairs completed eating behavior questionnaires and 13 discordant pairs (eight male and five female pairs) and nine concordant pairs (five male and four female pairs) provided a complete food diary. All pairs provided 3-day PA diaries. Eight discordant pairs underwent DLW measurements. The study protocols were approved by the institutional review boards of Indiana University, Bloomington, USA; the University of Helsinki, Finland and the Hospital District of Helsinki and Uusimaa, Finland. All participants gave written informed consent.

Methods

Anthropometric measurements. Weight and height were measured in a fasting state barefoot in light clothing.[21–25] Percent body fat was measured by dual-energy X-ray absorptiometry[25] (Lunar Prodigy, Madison, WI, USA, software version 8.8).

Eating behavior questionnaires. To assess obesity-related eating habits, the participants were asked to choose one of four options that best characterized their overall eating style ('normal,' overeating, restrictive eating or alternating overeating and restricting).[27] Further, a short 12-item questionnaire was devised with five items assessing snacking/grazing styles, three items assessing health-conscious eating, two items assessing emotional eating, one item assessing externally cued eating (eating triggered by seeing food or advertisements of food, etc.) and night eating, respectively.[27] For each of the items, the participants were asked to circle the alternative that best describes him/her by using the response alternatives usually, often, sometimes or rarely. In the analyses, usually and often were combined, and sometimes or rarely were combined.

In addition, three validated tests were used for evaluation of eating behavior. Body dissatisfaction, drive for thinness and bulimia subscales from Eating Disorder Inventory were used to evaluate body image and psychological and behavioral aspects of eating.[28] The Drive for Thinness and Bulimia subscales both consisted of seven items and the body dissatisfaction subscale consisted of eight items. The Eating Disorder Inventory responses were scored 1 to 6 and required respondents to answer whether each item applies always, usually, often, sometimes, rarely or never. The most extreme eating disorder-like response was given a score of 3, followed by scores of 2 and 1 for the adjacent responses. The three other responses earned a score of 0. Total scores per subscale were obtained by summing all item scores for the scale in question. An abbreviated 18-item version of Three-Factor Eating Questionnaire was used to assess the cognitive aspects of eating and eating behavior.[29–31] Responses to items on the Three-Factor Eating Questionnaire were scored from 1 to 4 and summed to obtain scores for Cognitive Restraint, Uncontrolled Eating and Emotional Eating. Binge Eating Scale was used to study binge eating and cognitive-emotional factors in eating by a summary score from 16 items.[32]

Three-day food diaries. Food consumption and total energy and macronutrient intake were evaluated with 3-day food diaries. All the records included two working days and one non-working day, usually from Thursday to Saturday. The subjects were instructed by a registered dietician to keep a record of all food and liquid intake and they were encouraged to keep the eating patterns as normal as possible despite the recording. Food consumption (expressed as grams of food per MJ of energy intake) and macronutrient intakes (expressed as percentages of total energy intake) were calculated by the dietician using the program DIET32, which is based on a national Finnish database for food composition.[33]

Three-day PA diaries. A 3-day PA record[34] was obtained simultaneously with the food diaries. Each subject was given a comprehensive description of how to use the activity diary. Each day was divided into 96 periods of 15 min each. For every 15 min period, the subjects were asked to assign the dominant PA performed to one of the following eight categories: 1 = sleeping or resting, 2 = sitting, 3 = standing, 4 = working at a very low intensity, 5 = working at a low intensity, 6 = working or exercising at a moderate intensity, 7 = working or exercising at a vigorous intensity and 8 = working or exercising at a very vigorous intensity. A mean activity score and the mean time spent in each activity category in minutes were calculated. Basal metabolic rate (BMR) of the individual subjects was estimated by recommended predictive equations.[35] Physical-activity ratios were assigned to each category in the activity diaries as follows: 1 (category 1), 1.2 (category 2), 1.4 (category 3), 1.6 (category 4), 2.8 (category 5), 3.8 (category 6), 5.1 (category 7) and 6.7 (category 8).[35] The amount of time spent in each activity category in hours was multiplied by the energetic cost of the activity (PAR), summed up and divided by 24 to obtain the PA level. TEE from the activity diaries was then estimated by multiplying the BMR by the PA level. Activity energy expenditure (AEE) was calculated as AEE = TEE − BMR − (0.1TEE).

Doubly labeled water. The accuracy of reported energy intake from the diaries was validated with TEE, measured by mass spectrometry on the excretion of DLW in urine as described in detail in the Maastricht protocol.[36] The measurement was performed in a free-living setting during 14 consecutive days after leaving the study center.[37] The measurements were simultaneous with the 3-day food and PA diary collections. Underreporting of energy intake was defined as TEE (DLW) − energy intake. Overreporting of PA was defined as TEE (activity diaries) − TEE (DLW).

Co-twin comparison questionnaire. Co-twin comparisons of eating behavior were assessed by a questionnaire, in which the subjects were asked to compare their own eating behavior and PA with their co-twin's behavior during the last 12 months. 'Which one of you' was asked for 10 statements listed in the Appendix with response alternatives 'me, my co-twin, there is no difference between us, do not know.' Each co-twin was studied on separate days, and they had no contact with each other when answering the questionnaires.

Statistical methods

The differences between the co-twins were tested by Wilcoxon's-matched pairs signed ranks test in case of continuous variables and by symmetry test in case of categorical variables. Wilcoxon's test was also used to analyze whether underreporting was significantly different from zero. Co-twin comparisons of eating habits and PA patterns (Appendix) were presented as descriptive data (Figure 3a and 3b). Relationships between underreporting and food and nutrient intake in individual twins were calculated by Pearson's correlations and regression models for complex survey data because this allowed correction for clustered sampling of co-twins within pairs.[38] Non-normally distributed data was logarithmically (ln) transformed. The statistical analyses were performed using the Stata statistical software (release 9.0; Stata Corporation, College Station, TX, USA). Data are presented as mean values and ± s.e.

Results

Selected characteristics

Clinical characteristics of obesity-discordant and weight-concordant MZ pairs are presented in Table 1. Analyses of eating behavior were performed among obesity-discordant MZ pairs with significant differences in weight (mean 15.0 kg) and BMI (5.2 kg m^{-2}) ($P < 0.001$, Table 1) and among concordant MZ pairs with similar weights (2.6 kg) and BMIs (1.0 kg m^{-2}) within co-twins.

Eating behavior

Obesity-related eating behavior. was assessed by a questionnaire that addressed restrictive/overeating, snacking, health-conscious, emotional and externally induced eating styles.[27] Most (61%) of the obese co-twins reported eating too much, whereas only 21% of non-obese co-twins reported doing so (symmetry test between the co-twins $P = 0.014$). Attempts to maintain healthy eating patterns 'usually' or 'often' tended to be less frequent in obese than in non-obese co-twins (50 vs 86%, $P = 0.059$). The other items did not differ between obese and non-obese co-twins. Many twins tried to avoid fat (50% of the obese, 64% of the non-obese), but only few tried to avoid calories (21% of the obese, 29% of the non-obese). In the concordant pairs, there were no differences between the co-twins in these items (data not shown).

Body Dissatisfaction and Drive for Thinness Scores were higher in obese than in non-obese co-twins (Figure 1). Bulimia sub-score was low and did not differ between the co-twins (Figure 1). There were no significant differences in the Three-Factor Eating Questionnaire sections for Cognitive

Table 1 Clinical characteristics of obesity-discordant and weight-concordant pairs

	MZ obesity-discordant pairs (n = 14)		*MZ weight-concordant pairs (n = 10)*
	Obese	*Non-obese*	*Both co-twins*
Age (years)	25.5 ± 0.3	25.5 ± 0.3	25.7 ± 0.3
Height (cm)	170 ± 2	170 ± 2	173 ± 2
Weight (kg)	88.8 ± 2.3	73.7 ± 2.3[a]	80.2 ± 4.7
BMI (kg m^{-2})	30.1 ± 0.5	25.4 ± 0.5[a]	26.8 ± 1.6
Percentage body fat (%)	38.3 ± 1.8	29.4 ± 2.3[a]	28.2 ± 2.9
TEE (MJ per day)[b]	12.4 ± 0.4	11.5 ± 0.7	NA
EI (MJ per day)[b]	9.6 ± 1.0	9.8 ± 1.1	8.2 ± 0.8[c]
Underreporting (TEE-EI) (MJ per day)[b]	3.2 ± 1.1[d]	0.8 ± 1.4	NA
Over-reporting of PA (TEE diaries-TEE DLW) (MJ per day)[b]	1.8 ± 0.8[d]	1.1 ± 0.6	NA

Abbreviations: BMI, body mass index; DLW, doubly labeled water; EI, energy intake; MZ, monozygotic; PA, physical activity; TEE, total energy expenditure. Data are mean ± s.e.m. [a]$P<0.001$, Wilcoxon's test between the obese and non-obese co-twins. [b]Eight obesity-discordant pairs had TEE measurements. Same pairs were selected for calculating EI and TEE from the food and activity diaries. [c]Nine concordant pairs kept food diaries. [d]$P<0.05$, significantly different from zero in the obese co-twins.

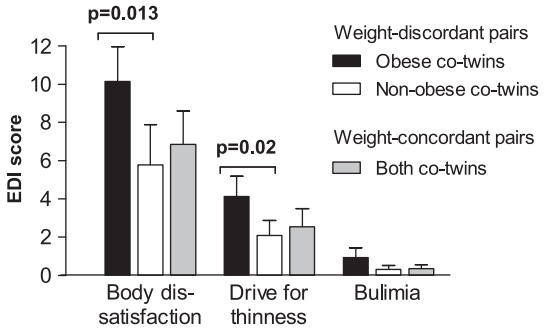

Figure 1 The Eating Disorder Inventory (EDI) scores for body dissatisfaction, drive for thinness and bulimia for the obesity-discordant ($n=14$) and weight-concordant ($n=10$) MZ twin pairs.

Restraint (mean and s.e.m.: 39.7 ± 3.7 vs 44.0 ± 5.4 in obese and non-obese, respectively), Uncontrolled Eating (34.7 ± 4.4 vs 33.1 ± 3.9) or Emotional Eating (34.1 ± 7.8 vs 35.7 ± 6.2) between the co-twins. As expected, bingeing was rare (Binge Eating Scale score 10.0 ± 2.2 vs 8.4 ± 1.6 in obese and non-obese co-twins, respectively). The concordant co-twins had similar scores on the parameters mentioned above.

Food diaries

Total energy intake did not differ between obese and non-obese co-twins (Table 1). Total fat intake was similar in the co-twins, but obese twin pair members had a significantly lower proportional intake of mono- and polyunsaturated fatty acids than non-obese counterparts. They also reported a significantly lower consumption of sweet and fatty delicacies than non-obese co-twins (Table 2). Obese co-twins reported a tendency to consume less fruits and berries ($P=0.08$). Dietary intake was similar in the concordant co-twins (mean intakes shown in Table 2).

Physical-activity diaries

The activity patterns of the obesity-discordant and concordant co-twins are shown in Table 3. The mean PA level did not differ significantly between obese and non-obese co-twins (1.74 ± 0.02 vs 1.79 ± 0.04 in obese and non-obese, respectively) or between co-twins of the concordant pairs. All twins spent most of their days in highly sedentary activities (categories 1 and 2). Analysis of the time spent in different activity categories per day revealed that non-obese co-twins exercised 7 ± 5 min daily at a very vigorous intensity (category 8), whereas none of the obese co-twins reported any engagement in very vigorous intensity exercise ($P=0.08$ between the co-twins). The non-obese co-twins also showed a tendency to spend more time in vigorous intensity exercise

Table 2 Food consumption (g MJ^{-1}) and macronutrient intake (% of energy, *E*%) of obesity-discordant and weight-concordant pairs

	MZ obesity-discordant pairs (n = 13)		*MZ weight-concordant pairs (n = 9)*
	Obese	*Non-obese*	*Both co-twins*
Food intake			
Grain products	16 ± 4	20 ± 6	17 ± 4
Potatoes, vegetables	38 ± 6	24 ± 5	34 ± 4
Fruits and berries	8 ± 3	12 ± 4[a]	13 ± 3
Milk products	45 ± 12	34 ± 9	70 ± 9
Cheese	4 ± 1	4 ± 1	7 ± 2
Meat products	18 ± 3	15 ± 2	14 ± 1
Fish, eggs and seafood	6 ± 2	5 ± 1	5 ± 1
Regular beverages	35 ± 8	24 ± 6	24 ± 4
Water and light beverages	122 ± 38	98 ± 23	87 ± 18
Alcoholic beverages	38 ± 18	26 ± 9	18 ± 8
Sweet delicacies, fat ⩽10% of energy	3 ± 1	6 ± 2[b]	7 ± 1
High-fat delicacies, fat >10% of energy	3 ± 1	7 ± 1[b]	2 ± 1
Macronutrient intake			
Fat	30.8 ± 2.0	33.9 ± 1.3	31.2 ± 1.9
Saturated fatty acids	12.2 ± 1.1	12.7 ± 0.8	12.6 ± 1.1
Monounsaturated fatty acids	8.6 ± 0.5	10.0 ± 0.4[b]	9.3 ± 0.5
Polyunsaturated fatty acids	3.8 ± 0.3	4.9 ± 0.5[b]	4.0 ± 0.2
Carbohydrates	48.9 ± 1.6	49.1 ± 1.3	48.9 ± 2.5
Protein	15.7 ± 1.1	14.6 ± 0.6	17.8 ± 0.6

Abbreviation: MZ, monozygotic. Data are mean ± s.e.m. [a]$P=0.08$. [b]$P<0.05$, Wilcoxon's test between the obese and non-obese co-twins.

Table 3 Mean time spent in different categories of physical activity in obesity-discordant ($n=14$) and weight-concordant ($n=10$) monozygotic twin pairs

	MZ obesity-discordant pairs (n = *14*)		*MZ weight-concordant pairs* (n = *10*)
	Obese	*Non-obese*	*Both co-twins*
Mean activity score	2.0 ± 0.1	2.1 ± 0.1	2.1 ± 0.1
Activity energy expenditure (MJ per day)	4.55 ± 0.22	4.39 ± 0.29	4.56 ± 0.22
Physical activity level (PAL)	1.74 ± 0.02	1.79 ± 0.04	1.79 ± 0.03
Activity categories (minutes per day)			
1	576 ± 14	561 ± 22	549 ± 20
2	553 ± 43	567 ± 63	586 ± 33
3	146 ± 27	118 ± 17	121 ± 23
4	85 ± 19	64 ± 17	73 ± 15
5	55 ± 23	105 ± 42	56 ± 14
6	23 ± 6	7 ± 3[a]	40 ± 14
7	3 ± 2	11 ± 5	5 ± 3
8	0 ± 0	7 ± 5[b]	10 ± 4

Abbreviation: MZ, monozygotic. Data are mean ± s.e.m. Activity categories: 1 = sleeping or resting; 2 = sitting; 3 = light activity standing; 4 = working at a very low intensity, 5 = working at a low intensity, 6 = working or exercising at a moderate intensity; 7 = working or exercising at a vigorous intensity and 8 = working or exercising at a very vigorous intensity. [a]$P<0.05$. [b]$P=0.08$, Wilcoxon's test between the obese and non-obese co-twins.

(category 7; 3 ± 2 vs 11 ± 5 min in obese and non-obese, respectively, $P=0.24$). Obese co-twins spent 16 more minutes a day exercising at a moderate intensity (category 6; $P=0.04$).

Doubly labeled water

Obese co-twins underreported their daily energy intake significantly by 3.2 ± 1.1 MJ per day, 25% of TEE ($P=0.036$). In non-obese co-twins, the difference between TEE and reported energy intake (0.8 ± 1.4 MJ per day, 8% of TEE) was non-significant (Table 1). Relative underreporting correlated with BMI in obese ($r=0.70$, $P=0.05$), but not in non-obese co-twins ($r=-0.26$, $P=0.54$). Underreporting was associated with a significantly lower consumption of high-fat delicacies ($r=-0.73$, $P=0.003$) and lower intakes of all macronutrients in grams per day (fat: $r=-0.79$, $P=0.006$; carbohydrates: $r=-0.84$, $P=0.001$; protein: $r=-0.54$, $P=0.049$) (Figure 2), but not significantly in proportions of energy intake (fat: $r=-0.21$; carbohydrates: $r=0.23$; protein: $r=0.31$). Underreporting was also associated with lower consumption of fish ($r=-0.50$, $P=0.015$) and fat-free milk ($r=-0.58$, $P=0.001$). Overreporting of PA was significant in obese (1.8 ± 0.8 MJ per day, $P=0.049$), but not in lean co-twins (1.1 ± 0.6, $P=0.12$) (Table 1).

Co-twin comparison questionnaire

The finding of a significant underreporting by the obese subjects (Table 1) is supported by the results of the co-twin comparison questions, in which both co-twins agreed on

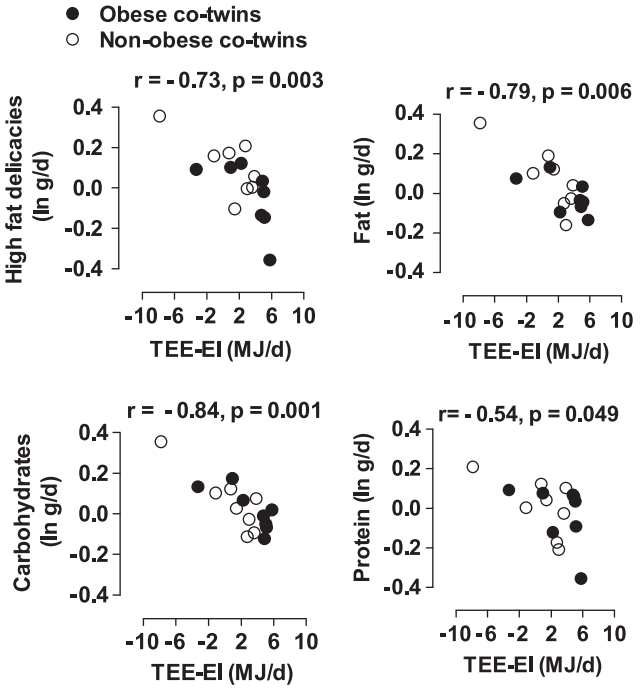

Figure 2 Pearson correlation between the log-transformed (ln) intake of high-fat delicacies and macronutrients (g per day) and the degree of underreporting (total energy expenditure (TEE)−total energy intake (EI), MJ per day) ($n=16$ individuals from eight obesity-discordant pairs).

that the obese co-twins habitually consume more food and more snacks than their leaner co-twins (Figure 3a). In addition, the co-twin assessments suggests that the obese co-twins underreported the intake of high-fat delicacies, as most of the leaner co-twins reported that the obese co-twins eat more fatty foods. None of the obese co-twins reported to eat healthier than their leaner co-twins and none of the leaner co-twins reported that their obese co-twins eat healthier. Leaner co-twins reported exercising and fidgeting more than obese co-twins (Figure 3b). No consistent differences were found between weight-concordant co-twins (data not shown).

Discussion

This study on MZ twins highly discordant for obesity represents an ideal model to identify differences in eating and PA patterns between obese and non-obese subjects independent of genetic effects. Co-twin assessments provide a powerful tool to objectively evaluate food intake and PA behaviors, which in prior research have been difficult to study because of substantial misreporting errors especially by obese subjects. In addition, we used state-of-the-art DLW methodology to confirm energy expenditure in these obesity-discordant twins.

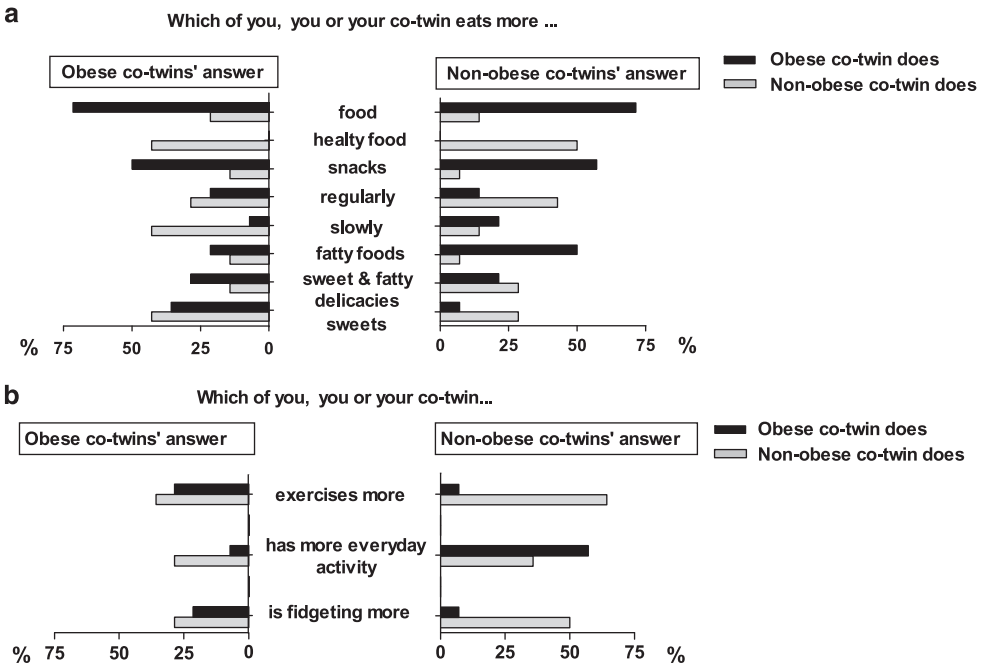

Figure 3 (**a** and **b**) Within-pair comparison of eating patterns and PA among obesity-discordant MZ twin pairs ($n=14$). The questions and response alternatives are shown in the Appendix. The co-twins were asked to rate themselves in relation to their co-twins: 'Which one of you…'

By using objective co-twin comparison questions, we found that most members of the discordant twin pairs independently reported that the heavier co-twins eat more, snack more and choose less healthy foods than their leaner co-twins. In addition, the majority of obese co-twins reported in the eating behavior questionnaire to eat habitually more than they actually need, whereas the majority of non-obese did not report so. Similarly, in our earlier study on another sample, middle-aged identical weight-discordant twins, a tendency to overeat was observed in the heavier co-twins.[17] Importantly, both co-twins recalled that this pattern, consisting of more calories, high-fat and sweet food and alcohol, had arisen already in early adulthood (age 20–30), before the development of weight discordance.[17]

Despite the recognition of diet as a major factor in the development and maintenance of obesity, neither the present nor earlier studies[6,39] have been able to find that energy intake assessed by food diaries is higher in obese than non-obese subjects. Studies comparing food intake data of obese and non-obese subjects are prone to differential reporting bias because obese and lean individuals report their food intake with differential levels of accuracy. It has been repeatedly shown that obese individuals are more likely than lean individuals to underreport or underestimate their food intake.[13,15,40] In this study, the obese co-twins underreported 3.2 MJ per day, 25% of their total energy expenditure, whereas the non-obese co-twins only underreported 0.8 MJ per day, 8% of their daily expenditure. Thus, differential reporting of food intake between obese and lean co-twins is a likely explanation why we did not observe differences in energy and macronutrient intake between co-twins in the food diaries. On the basis of a detailed study by Goris *et al.*,[13] it is likely that undereating during the collection period contributes more than underrecording (failure to record what is eaten) to the observed underreporting.

The underreporting of obese subjects may be macronutrient specific. Fat and carbohydrates have been found to be more likely underreported than protein.[41] Selective underreporting of fat[13,42] and both fatty and sweet foods[43] has earlier been observed in several populations. In this study, underreporting was directed to sweet and high-fat delicacies, which were reported less by those with more underreporting. Underreporting was associated with lower intakes of all macronutrients in absolute grams per day. In this study, proportional intakes of macronutrients from energy were not significantly affected by underreporting.

Intriguingly, although total and saturated-fat intake was similar in the obese and non-obese co-twins of this study, the obese co-twins consumed proportionally less monounsaturated and polyunsaturated fatty acids. This suggests that obese subjects may underreport high-fat foods, but do not overreport the consumption of foods that are generally considered healthy, such as unsaturated fatty acids. In line with this, we showed that obese co-twins tended to eat less fruits and berries (probably reflecting true smaller consumption).

High energy intake is not a prerequisite for weight gain if PA is low.[44] Accelerometer measurements from our earlier

study[37] showed that the obese co-twins were not even half as active as the non-obese co-twins. In contrast, the mean PA level in the PA diaries did not differ significantly between obese and non-obese co-twins. This might be due to the fact that obese individuals are likely to perceive and, therefore, rate a given activity as more intense than lean individuals.[45] In the PA diaries of this study, obese co-twins may have assigned a higher code than non-obese co-twins for the same activity, resulting in significant overreporting of PA by the obese, but not by the non-obese co-twins. We, therefore, suggest that PA diaries, similar to food diaries, are prone to misreporting in the obese. According to the accelerometer data,[37] PA diaries, however, were able to illustrate that among these young adult twins, high intensity activity is rare especially in the obese subjects. Non-obese co-twins spent 18 min daily performing vigorous activities (categories 7 and 8, representing working or exercising at a vigorous and very vigorous intensity), compared with only 3 min in obese-co-twins. Further, obese co-twins did not exercise at all at the highest intensity. We earlier reported that obese co-twins had significantly higher body mass and basal metabolic rate, but as their PA levels were significantly reduced, they did not have higher total or PA energy expenditure than the non-obese co-twins.[37]

This study is a very good example of MZ twins, who, despite their identical DNA sequences, exhibit different lifestyle behaviors (nutrition, PA) and metabolic conditions. As MZ twins are genetically identical at the sequence level and share the same family environment, discordance on a trait can be explained by differences in the non-shared environment (that is environmental factors that are unique to each member of a twin pair). Such non-shared environmental factors include, for example, different friends, differential parental treatment, specific life events, prenatal exposures and exposures to infectious agents. An alternative explanation for the differential development between genetically identical individuals involves epigenetic modification that can lead to differential expression of genes in MZ twin pairs.[23,46]

MZ twin pairs discordant for obesity provide a powerful tool to determine the contribution of eating and PA habits to obesity. The use of MZ co-twins provides complete matching of obese and non-obese groups for genetic factors (DNA sequence), age and gender and close matching for intrauterine and childhood environmental factors. However, such pairs are very rare, which resulted in a fairly small sample size. Screening five nationally representative birth cohorts of young adult twins ($n = 658$ pairs) yielded only 14 pairs discordant for obesity. The difficulty of finding MZ pairs discordant for obesity speaks for a strong genetic basis for obesity[47] and perhaps for eating patterns.[48] The small sample size likely limited our power to detect significant differences between obesity-discordant co-twins. Further, this study was performed in a healthy population with a narrow age range (23–28 years old) and may not be generalizable to other age groups or to persons with an illness. The cross-sectional design of this study does not allow causal conclusions to be drawn. However, in our earlier analysis of the sample, there was direct prospective evidence that differences in PA preceded development of weight differences.[37] Prospective data on food intake was not available. In this study, we combined the use of co-twin assessments and the opportunity to validate self-reported energy intake from the food diaries against DLW, a golden standard for energy expenditure.[18,19] This approach significantly improved the strength of our findings regarding obese subject's eating habits.

In conclusion, our results suggest that obese and non-obese subjects differ significantly in their eating and PA behavior. Obesity is associated with eating more, snacking more and choosing less healthy foods, whereas exercising less at high intensities. The DLW measurements showed significant underreporting of energy intake and over-reporting of PA by the obese co-twins. We, therefore, suggest that food and PA diaries do not provide accurate measures of usual dietary and activity habits and should not be used as evidence that eating and activity patterns do not contribute to the etiology and maintenance of obesity.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

We wish to thank all the volunteers, and Erjastiina Heikkinen, Taija Kivimäki and Anna-Maija Tiainen. The study was supported by the National Institute on Alcohol Abuse and Alcoholism (grants AA-08315, AA-00145 and AA-12502), the European Union Fifth Framework Program (QLRT-1999-00916, QLG2-CT-2002-01254), DiOGenes project, the Academy of Finland (Grant 44069, 100499 and 201461), the Academy of Finland Centre of Excellence in Complex Disease Genetics, Helsinki University Central Hospital grants, and grants from Yrjö Jahnsson Foundation, Jalmari and Rauha Ahokas Foundation, Juho Vainio Foundation, Finnish Cultural Foundation, Finnish Medical Foundation and Research Foundation of the Orion Corporation. DiOGenes is the acronym of the project 'Diet, Obesity and Genes' supported by the European Community (Contract no. FOOD-CT-2005-513946).

References

1 WHO. Diet, nutrition and the prevention of chronic diseases. Report of the joint WHO/FAO expert consultation. WHO Technical Report Series, No. 916 (TRS 916). Geneva: World Health Organization, 2003.
2 Andersson I, Rossner S. Meal patterns in obese and normal weight men: the 'Gustaf' study. *Eur J Clin Nutr* 1996; **50**: 639–646.

3 Davis JN, Hodges VA, Gillham MB. Normal-weight adults consume more fiber and fruit than their age- and height-matched overweight/obese counterparts. *J Am Diet Assoc* 2006; **106**: 833–840.
4 Duvigneaud N, Wijndaele K, Matton L, Philippaerts R, Lefevre J, Thomis M *et al*. Dietary factors associated with obesity indicators and level of sports participation in Flemish adults: a cross-sectional study. *Nutr J* 2007; **6**: 26.
5 Fung TT, Rimm EB, Spiegelman D, Rifai N, Tofler GH, Willett WC *et al*. Association between dietary patterns and plasma biomarkers of obesity and cardiovascular disease risk. *Am J Clin Nutr* 2001; **73**: 61–67.
6 Hassapidou M, Fotiadou E, Maglara E, Papadopoulou SK. Energy intake, diet composition, energy expenditure, and body fatness of adolescents in northern Greece. *Obesity (Silver Spring)* 2006; **14**: 855–862.
7 Jackson M, Walker S, Forrester T, Cruickshank JK, Wilks R. Social and dietary determinants of body mass index of adult Jamaicans of African origin. *Eur J Clin Nutr* 2003; **57**: 621–627.
8 Kant AK, Graubard BI. Energy density of diets reported by American adults: association with food group intake, nutrient intake, and body weight. *Int J Obes (Lond)* 2005; **29**: 950–956.
9 Ledikwe JH, Blanck HM, Kettel Khan L, Serdula MK, Seymour JD, Tohill BC *et al*. Dietary energy density is associated with energy intake and weight status in US adults. *Am J Clin Nutr* 2006; **83**: 1362–1368.
10 Ortega RM, Requejo AM, Andres P, Lopez-Sobaler AM, Redondo R, Gonzalez-Fernandez M. Relationship between diet composition and body mass index in a group of Spanish adolescents. *Br J Nutr* 1995; **74**: 765–773.
11 Vagstrand K, Barkeling B, Forslund HB, Elfhag K, Linne Y, Rossner S *et al*. Eating habits in relation to body fatness and gender in adolescents—results from the 'SWEDES' study. *Eur J Clin Nutr* 2007; **61**: 517–525.
12 Sasaki S, Katagiri A, Tsuji T, Shimoda T, Amano K. Self-reported rate of eating correlates with body mass index in 18-y-old Japanese women. *Int J Obes Relat Metab Disord* 2003; **27**: 1405–1410.
13 Goris AH, Westerterp-Plantenga MS, Westerterp KR. Undereating and underrecording of habitual food intake in obese men: selective underreporting of fat intake. *Am J Clin Nutr* 2000; **71**: 130–134.
14 Voss S, Kroke A, Klipstein-Grobusch K, Boeing H. Is macronutrient composition of dietary intake data affected by under-reporting? Results from the EPIC-Potsdam Study. European Prospective Investigation into Cancer and Nutrition. *Eur J Clin Nutr* 1998; **52**: 119–126.
15 Heitmann BL, Lissner L, Osler M. Do we eat less fat, or just report so? *Int J Obes Relat Metab Disord* 2000; **24**: 435–442.
16 Hakala P, Rissanen A, Koskenvuo M, Kaprio J, Rönnemaa T. Environmental factors in the development of obesity in identical twins. *Int J Obes Relat Metab Disord* 1999; **23**: 746–753.
17 Rissanen A, Hakala P, Lissner L, Mattlar CE, Koskenvuo M, Rönnemaa T. Acquired preference especially for dietary fat and obesity: a study of weight-discordant monozygotic twin pairs. *Int J Obes Relat Metab Disord* 2002; **26**: 973–977.
18 Hill RJ, Davies PS. The validity of self-reported energy intake as determined using the doubly labelled water technique. *Br J Nutr* 2001; **85**: 415–430.
19 Trabulsi J, Schoeller DA. Evaluation of dietary assessment instruments against doubly labeled water, a biomarker of habitual energy intake. *Am J Physiol Endocrinol Metab* 2001; **281**: E891–E899.
20 Kaprio J. Twin studies in Finland 2006. *Twin Res Hum Genet* 2006; **9**: 772–777.
21 Gertow K, Pietiläinen KH, Yki-Järvinen H, Kaprio J, Rissanen A, Eriksson P *et al*. Expression of fatty-acid-handling proteins in human adipose tissue in relation to obesity and insulin resistance. *Diabetologia* 2004; **47**: 1118–1125.
22 Kannisto K, Pietiläinen KH, Ehrenborg E, Rissanen A, Kaprio J, Hamsten A *et al*. Overexpression of 11beta-hydroxysteroid dehydrogenase-1 in adipose tissue is associated with acquired obesity and features of insulin resistance: studies in young adult monozygotic twins. *J Clin Endocrinol Metab* 2004; **89**: 4414–4421.
23 Pietiläinen KH, Kannisto K, Korsheninnikova E, Rissanen A, Kaprio J, Ehrenborg E *et al*. Acquired obesity increases CD68 and tumor necrosis factor-alpha and decreases adiponectin gene expression in adipose tissue: a study in monozygotic twins. *J Clin Endocrinol Metab* 2006; **91**: 2776–2781.
24 Pietiläinen KH, Rissanen A, Kaprio J, Mäkimattila S, Hakkinen AM, Westerbacka J *et al*. Acquired obesity is associated with increased liver fat, intra-abdominal fat, and insulin resistance in young adult monozygotic twins. *Am J Physiol Endocrinol Metab* 2005; **288**: E768–E774.
25 Pietiläinen KH, Bergholm R, Rissanen A, Kaprio J, Hakkinen AM, Sattar N *et al*. Effects of acquired obesity on endothelial function in monozygotic twins. *Obesity (Silver Spring)* 2006; **14**: 826–837.
26 Pietiläinen KH, Rissanen A, Laamanen M, Lindholm AK, Markkula H, Yki-Järvinen H *et al*. Growth patterns in young adult monozygotic twin pairs discordant and concordant for obesity. *Twin Res* 2004; **7**: 421–429.
27 Keski-Rahkonen A, Bulik CM, Pietiläinen KH, Rose RJ, Kaprio J, Rissanen A. Eating styles, overweight and obesity in young adult twins. *Eur J Clin Nutr* 2007; **61**: 822–829.
28 Garner DM. *Eating Disorder Inventory 2, Professional Manual*. Psychological Assessment Resources: Odessa, FL, 1991.
29 Bond MJ, McDowell AJ, Wilkinson JY. The measurement of dietary restraint, disinhibition and hunger: an examination of the factor structure of the Three Factor Eating Questionnaire (TFEQ). *Int J Obes Relat Metab Disord* 2001; **25**: 900–906.
30 Karlsson J, Persson LO, Sjöström L, Sullivan M. Psychometric properties and factor structure of the Three-Factor Eating Questionnaire (TFEQ) in obese men and women. Results from the Swedish Obese Subjects (SOS) study. *Int J Obes Relat Metab Disord* 2000; **24**: 1715–1725.
31 Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *J Psychosom Res* 1985; **29**: 71–83.
32 Gormally J, Black S, Daston S, Rardin D. The assessment of binge eating severity among obese persons. *Addict Behav* 1982; **7**: 47–55.
33 National Institute for Health and Welfare. Nutrition Unit. Fineli. Finnish food composition database. Release 9. Helsinki 2009. http://www.fineli.fi.
34 Bouchard C, Tremblay A, Leblanc C, Lortie G, Savard R, Theriault G. A method to assess energy expenditure in children and adults. *Am J Clin Nutr* 1983; **37**: 461–467.
35 FAO/WHO/UNU. Energy and protein requirements. Report of a joint FAO/WHO/UNU expert consultation. Technical report series 724. Geneva: World Health Organization, 1985.
36 Westerterp KR, Wouters L, van Marken Lichtenbelt WD. The Maastricht protocol for the measurement of body composition and energy expenditure with labeled water. *Obes Res* 1995; **3**: 49–57.
37 Pietiläinen KH, Kaprio J, Borg P, Plasqui G, Yki-Järvinen H, Kujala UM *et al*. Physical inactivity and obesity: a vicious circle. *Obesity (Silver Spring)* 2008; **16**: 409–414.
38 Rao JNK, Scott AK. On chi-squared tests for mulitway contingency tables with cell proportions estimated from surbey data. *Ann Stat* 1984; **12**: 46–60.
39 Rennie KL, Siervo M, Jebb SA. Can self-reported dieting and dietary restraint identify underreporters of energy intake in dietary surveys? *J Am Diet Assoc* 2006; **106**: 1667–1672.
40 Westerterp KR, Goris AH. Validity of the assessment of dietary intake: problems of misreporting. *Curr Opin Clin Nutr Metab Care* 2002; **5**: 489–493.
41 Lissner L. Measuring food intake in studies of obesity. *Public Health Nutr* 2002; **5**: 889–892.
42 Heitmann BL, Lissner L. Dietary underreporting by obese individuals—is it specific or non-specific? *BMJ* 1995; **311**: 986–989.

43 Macdiarmid JI, Vail A, Cade JE, Blundell JE. The sugar-fat relationship revisited: differences in consumption between men and women of varying BMI. *Int J Obes Relat Metab Disord* 1998; **22**: 1053–1061.
44 Roberts SB, Leibel RL. Excess energy intake and low energy expenditure as predictors of obesity. *Int J Obes Relat Metab Disord* 1998; **22**: 385–386.
45 Kesaniemi YA, Danforth E, Jensen MD, Kopelman PG, Lefebvre P, Reeder BA. Dose-response issues concerning physical activity and health: an evidence-based symposium. *Med Sci Sports Exerc* 2001; **33**: s351–s358.
46 Fraga MF, Ballestar E, Paz MF, Ropero S, Setien F, Ballestar ML *et al*. Epigenetic differences arise during the lifetime of monozygotic twins. *Proc Natl Acad Sci USA* 2005; **102**: 10604–10609.
47 Korkeila M, Kaprio J, Rissanen A, Koskenvuo M. Effects of gender and age on the heritability of body mass index. *Int J Obes* 1991; **15**: 647–654.
48 Keskitalo K, Silventoinen K, Tuorila H, Perola M, Pietiläinen KH, Rissanen A *et al*. Genetic and environmental contributions to food use patterns of young adult twins. *Physiol Behav* 2008; **93**: 235–242.

Appendix

Which of you, you or your co-twin…
Eats more
Eats healthier food
Eats more snacks
Eats more regularly
Eats more slowly
Eats more fatty foods
Eats more sweet and fatty delicacies (chocolate, pastries, ice cream)
Eats more sweets (candies or jellies)
Is more worried about appearance
Goes on diets more often
Exercises more
Walks instead of taking a car or elevator, or makes other 'active' choices in daily life
Makes more movement during normal non-exercise activities (that is fidgeting)
Response alternatives were 'me, my co-twin, there is no difference between us, do not know'