Satiety quotient linked to food intake and changes in anthropometry during menopause: a MONET study

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Abstract:

Objectives: It is unknown whether the satiety quotient (SQ) differs across the menopausal transition, and whether changes in SQ are related to changes in anthropometric/body composition variables. The objective of this study was to evaluate the changes in SQ and its association with energy intake and changes in anthropometric/body composition variables across the menopausal transition. **Methods:** At baseline, 102 premenopausal women (aged 49.9 ± 1.9 years, body mass index 23.3 ± 2.2 kg/m^2) took part in a 5-year observational, longitudinal study. Body composition (DXA), appetite (visual analog scales), energy and macronutrient intakes (*ad libitum* lunch and 7-day food diary) were assessed annually. The SQ (mm/100 kcal) was calculated at 60 and 180 min post-breakfast consumption. **Results:** Overall, the SQ increased at years 3 and 4 (p = 0.01–0.0001), despite no significant differences between menopausal status groups. Lower fullness, prospective food consumption and mean SQ values predicted overall increases in lunch energy and macronutrient intakes (p = 0.04–0.01), whereas only prospective food consumption and fullness SQ predicted energy intake and carbohydrate intake, respectively, when assessed with food diaries (p = 0.01). Delta SQs were negatively correlated with changes in waist circumference (p = 0.03–0.02), whereas delta SQs were positively (p = 0.04) and negatively (p = 0.02) associated with delta fat mass between years 1 and 5, and years 4 and 5, respectively. **Conclusion:** These results suggest that variations in SQ across the menopausal transition are related to energy and macronutrient intakes and coincide with changes in body composition and waist circumference.

Keywords: satiety quotient | energy intake | body weight | waist circumference | fat mass

Article:

INTRODUCTION

Current evidence associates the menopausal transition with weight and fat mass gains over time [1], [2]. One plausible explanation for this association may be the increase in appetite ratings recently noted during the menopausal transition [3]. However, this study, and others [4], [5] also noted decreases in energy intake (EI) across the menopausal transition.

The satiety quotient (SQ), a valid marker of satiety efficiency in response to a standardized meal, can be used to determine the extent to which a standardized meal may reduce appetite sensations and is expressed per unit of EI (kcal) [6]. A lower fullness SQ, or smaller changes in subjective fullness ratings in response to a standardized meal, has been associated with increased EI in normal-weight, obese and weight-reduced individuals [7], [8]. Furthermore, individuals characterized with a low satiety phenotype (i.e. individuals with a mean SQ < 8 mm/100 kcal) had lower cortisol responses to a standardized meal, and short-duration sleepers (< 7 h of sleep/night) had a lower mean SQ compared to sleepers with a 'recommended' sleep duration (≥ 7 h of sleep/night) [10]. The presence of these two factors has also been previously associated with increased EI and potential weight gain over time [11]. It is, however, unknown whether the changes in subjective appetite sensations in response to a standardized meal, or SQ, may differ across the menopausal transition. Furthermore, it is unknown whether changes in SQ may be related to changes in anthropometric/body composition variables, in addition to EI during this period.

Hence, the objective of this study was to evaluate the changes in SQ in response to a standardized meal, and its potential association with subsequent EI across the menopausal transition through secondary analyses. Additionally, the present study assessed whether changes in SQ across the menopausal transition were associated with changes in anthropometric/body composition variables. We hypothesized that a decrease in SQ would occur during the menopausal transition, which would subsequently lead to a greater acute and daily EI at this time. We further hypothesized that decreases in SQ would be associated with increases in body weight, fat mass and waist circumference.

METHODS AND PROCEDURES

Participants

Participants were recruited using community advertising and referrals from Ob/Gyn clinics. The recruited premenopausal women adhered to the following inclusion criteria: (1) premenopausal status (two menstruations in the last 3 months, no increase in cycle irregularity 12 months before testing, and a plasma follicle stimulating hormone (FSH) level < 30 IU/l as a means of verification); (2) aged between 47 and 55 years; (3) non-smoker; (4) body mass index (BMI) between 20 and 29 kg/m^2; and (5) stable weight (± 2 kg) for at least 6 months prior to recruitment. The exclusion criteria were: (1) pregnancy or planning to become pregnant; (2) medical problems which may interfere with the outcome variables, such as cardiovascular and/or metabolic diseases; (3) taking oral contraceptives or hormonal therapy; (4) high risk for hysterectomy; and (5) history of drug and/or alcohol abuse. Further details on the design of the MONET menopausal transition study and recruitment procedures are provided elsewhere[2].

Figure 1 summarizes the number of participants who completed each outcome measurement during each year. However, it is important to note that only the participants who completed the appetite assessments each year over the 5-year period were included in the analyses (n = 42 when the SQ is assessed at 60 min and n = 39 when the SQ is assessed at 180 min). This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and the University of Ottawa and Montfort Hospital ethics committees approved all procedures involving human participants. Written informed consent was obtained from all participants.

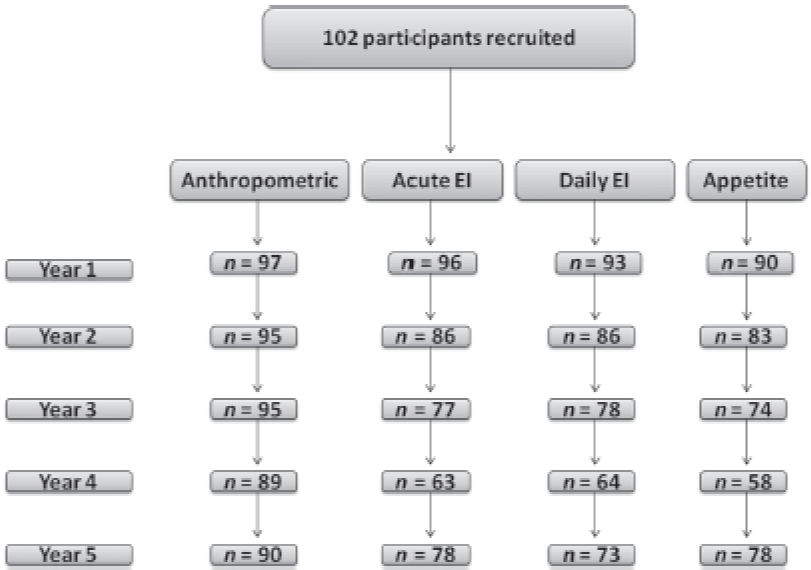

Figure 1. An overview of the number of participants that took part in each measurement during each year. EI, energy intake

Design and procedure

This observational, longitudinal study assessed all outcomes annually for 5 years (2004–2009). Premenopausal women were always tested on days 1–8 of the menstrual cycle. All outcomes were assessed at the same time of day each year. Participants were asked to refrain from the practice of vigorous exercise and alcohol consumption for at least 24 h prior to the start of each session.

Menopausal status

A yearly self-reported questionnaire was used to assess menstrual cycle regularity and determine menopausal status. FSH levels during the follicular phase were assessed yearly to confirm self-reported menopausal status. Women were classified as *premenopausal* if they reported no changes in menstrual cycle frequency, and in *menopausal transition* if they reported irregular cycles characterized by variable cycle lengths that were 7 days greater than normal and/or had ≥ two skipped cycles and an interval of ≥ 60 days of amenorrhea. Finally, women were classified as *postmenopausal* based on their final menstrual cycle period, which was confirmed by 12 months of amenorrhea and a FSH level > 30 IU/l [15].

Anthropometric measurements

Participants were weighed upon arrival to the nearest 0.1 kg with a BWB-800AS digital scale. Standing height was measured to the nearest centimeter using a wall stadiometer, Tanita HR-100 height rod, without shoes (Tanita Corporation of America, Inc.). Body composition was assessed with DXA (Lunar Prodigy, General Electric, Madison, WI, USA). The coefficient of variation and correlation for body fat percentage assessed in 12 healthy participants tested in our laboratory were 1.8% and $r = 0.99$, respectively.

Standardized breakfast and satiety quotient calculation

A standardized breakfast was served at 09.15. This breakfast contained whole-wheat bread (80 g), peanut butter (36 g), raspberry jam (32 g), cheddar cheese (21 g) and orange juice (240 g), and had a caloric content of 575 kcal and a food quotient of 0.89 (57% carbohydrates, 13% proteins and 30% lipids). The participants were instructed to consume the entire meal in 15 min. The participants' appetite sensations were recorded with visual analog scales (VAS) before, immediately after (time 0), and every 30 min (30, 60, 90, 120, 150 and 180 min) for 3 h post-breakfast consumption. The 150-mm VAS [16] were used to answer four specific questions that quantify subjective appetite sensations: desire to eat ('How strong is your desire to eat?'), hunger ('How hungry do you feel?'), fullness ('How full do you feel?'), and prospective food consumption (PFC) ('How much food do you think you could eat?'). The SQ was calculated for each appetite sensation at 60 and 180 min following breakfast consumption using the following equation adapted from Green and colleagues [17]: SQ (mm/100 kcal) = {[fasting appetite sensation (mm) = mean post-meal appetite sensation (mm)]/energy content of the test meal (kcal)} × 100.

It is important to note that the SQ calculation for the fullness rating is reversed (i.e. mean post-meal fullness rating = fasting fullness rating). The mean SQ, determined as the mean value of SQ scores for the four appetite sensations, was also calculated.

The SQ calculation has been shown to have a good reliability when assessed under controlled laboratory conditions, with the intra-class correlation coefficient value ($r = 0.67$) being greatest for mean SQ [9]. The possible range for SQ values in the current study is between − 26.1 and 26.1 mm/100 kcal. A higher SQ indicates a greater satiety response to a meal [8].

Energy and macronutrient intake measurements

An *ad libitum* lunch meal, as previously described by Arvaniti and colleagues [18], was offered to the participants at 12.30. The participants had 30 min to consume 'as little or as much as they wanted'. All food items were weighed before and after the participants consumed the test meal to the nearest gram. Following the in-laboratory assessment, participants completed a 7-day food diary to assess habitual daily energy and macronutrient intakes. The participants received oral and written instructions on how to record their food and beverage intakes. Recorded data were carefully verified with each participant when the food diary was returned to laboratory personnel to correct for misreported data, to obtain additional information and/or to add information if data were missing. The energy, protein, lipid and carbohydrate intakes from the *ad libitum* test meal and the 7-day food diary were calculated with the Food Processor SQL program (version 10.8; ESHA Research, Salem, OR, USA) using the 2007 Canadian Nutrient Data File.

Statistical analyses

Statistical analyses were performed using SPSS (version 17.0; SPSS Inc, Chicago, IL, USA). Two-way repeated measures ANOVA with menopausal status assessed at years 2, 3, 4 and 5 as the between-subject variable were used to determine the main effects of time (years 1–5) on desire to eat, hunger, fullness, PFC and mean SQ. A one-way ANOVA was used to determine the main effects of all SQ variables assessed at 60 min on anthropometric/body composition variables during each year, according to tertiles. *Post-hoc* tests with Bonferroni adjustments were used to determine where significant differences existed. The reported menopausal status at year 1 was not included in the analyses since all participants were premenopausal at this time. There was also only one premenopausal participant at year 4 who completed all appetite assessments during years 1–5, who was consequently added to the menopausal transition group for that year. Furthermore, the potential differences in all SQ variables based on menopausal status at year 5 (remained premenopausal/ in menopausal transition vs. postmenopausal for less than 12 months vs. postmenopausal for more than 12 months) were also assessed. Only participants who completed the appetite assessments over the 5-year period were included in the analyses.

Bivariate Spearman correlations were used to assess the strength of the relationships between desire to eat, hunger, fullness, PFC and mean SQ with acute and daily energy and macronutrient intakes for each year. All energy and macronutrient intake variables that were significantly correlated (p values < 0.05) with SQ variables during each year were included in a multivariate stepwise regression analyses. Bivariate Spearman correlations were used to assess whether the changes in desire to eat, hunger, fullness, PFC and mean SQ (delta year 1–2, 1–3, 1–4, 1–5, 2–3, 2–4, 2–5, 3–4, 3–5 and 4–5) were associated with the changes in anthropometric parameters between years. Data are presented as means ± standard deviations and effects with p values <0.05 were considered statistically significant.

RESULTS

As previously described [2], a significant main effect of time was noted for fat mass, indicating an overall increase over time. Conversely, overall decreases in daily (7-day food diary) energy, lipid and protein intakes were noted over time, as previously described [3]. Lastly, no changes in acute *ad libitum* energy and macronutrient intakes were observed over time [3].

As expected, all SQ variables were significantly greater when assessed at 60 vs. 180 min during years 1–5 (results not shown). Except for fullness SQ at 60 min and PFC SQ at 60 and 180 min, significant differences in all SQ variables were noted across time (Table 1). However, there were no differences in all SQ variables between menopausal status groups (premenopausal, menopausal transition and postmenopausal) assessed at years 2–5 (results not shown). Additionally, no significant differences in all SQ variables were observed between participants classified as (1) premenopausal/menopausal transition, (2) postmenopausal for less than 12 months, and (3) postmenopausal for more than 12 months, when assessed at year 5 (results not shown).

Table 1. Satiety quotient (SQ) for each appetite rating at 60 and 180 min assessed at years 1–5

	Year 1		Year 2		Year 3		Year 4		Year 5		
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Time effect**
60 minutes (n = 42)											
Desire to eat SQ*	10.8	7.6	12.8	6.7	14.5	5.8	15.3	7.7	10.2	5.3	F (4) = 7.8; p = 0.0001
Hunger SQ†	10.8	6.1	11.7	6.9	13.5	5.8	13.8	7.3	13.4	6.5	F (4) = 3.4; p = 0.01
Fullness SQ	14.1	7.1	15.3	8.1	16.3	6.3	17.3	6.7	15.7	7.3	F (4) = 2.4; p = 0.05
PFC SQ	9.6	5.0	10.0	5.7	10.7	4.3	12.0	6.4	11.5	5.5	F (4) = 2.3; p = 0.06
Mean SQ‡	11.3	5.2	12.5	5.8	13.8	4.5	14.6	6.3	12.7	5.3	F (4) = 4.8; p = 0.001
180 minutes (n = 39)											
Desire to eat SQ**	8.5	7.7	10.5	7.0	12.4	5.6	− 2.9	2.8	10.5	7.4	F (4) = 51.1; p = 0.0001
Hunger SQ††	8.2	6.1	9.2	6.7	11.0	5.6	11.8	6.7	10.3	6.8	F (4) = 4.1; p = 0.003
Fullness SQ††	11.6	6.6	13.3	7.1	13.5	6.4	15.3	6.4	12.7	7.0	F (4) = 3.3; p = 0.01
PFC SQ	7.4	5.0	7.4	5.3	7.8	3.8	9.7	6.0	8.4	4.9	F (4) = 2.4; p = 0.06
Mean SQ‡	8.9	5.2	10.1	5.7	11.2	4.3	8.5	4.2	10.5	5	F (4) = 3.8; p = 0.01

SD, standard deviation; PFC, prospective food consumption
*, $p < 0.01$ between years 1 and 4, years 3 and 5, and years 4 and 5; †, $p < 0.05$ between years 1 and 4; ‡, $p < 0.05$ between years 4 and 5, years 1 and 3, and years 2 and 4 and $p < 0.001$ between years 1 and 4 (60 min) and between years 3 and 4 (180 min); **, $p < 0.001$ between years 1 and 4, years 2 and 4, years 3 and 4, and years 4 and 5; ††, $p < 0.01$ between years 1 and 4

Table 2. The amount of variance (R^2) and the regression coefficient (β) for statistically significant associations between satiety quotient (SQ) variables with acute (ad libitum lunch) and daily (7-day food diary) energy and macronutrient intakes assessed at years 1–5

	Acute								**Daily**			
	Energy		**Carbohydrate**		**Lipid**		**Protein**		**Energy**		**Carbohydrate**	
	R²	**β**	**R²**	**β**	**R²**	**β**	**R²**	**β**	**R²**	**β**	**R²**	**β**
60 minutes												
Fullness SQ												
Year 3	0.07	–0.26*	0.06	–0.25*								
Year 4							0.07	–0.27*			0.08	–0.28*
PFC SQ												
Year 4									0.13	–0.36*		
Year 5	0.11	–0.33**			0.06	–0.25*	0.12	–0.35**				
Mean SQ												
Year 5	0.06	–0.24*					0.07	–0.27*				
180 minutes												
Fullness SQ												
Year 1							0.05	–0.23*				
Year 3	0.10	–0.32*	0.08	–0.28*	0.09	–0.29*	0.08	–0.29*				
Year 4							0.08	–0.28*				
PFC SQ												
Year 4									0.14	–0.37*		
Year 5	0.08	–0.29*					0.07	–0.26*				
Mean SQ												
Year 5							0.05	–0.23*				

PFC, prospective food consumption *, $p < 0.05$; **, $p < 0.01$

Table 2 summarizes the statistically significant associations between different SQ variables with acute and daily energy and macronutrient intakes. Briefly, the fullness, PFC and mean SQ explained between 5 and 14% of the variance in *ad libitum* energy and macronutrient intake at lunch at every year of assessment, except for year 2. Furthermore, the fullness and PFC SQ explained between 8 and 14% of the variance in daily (7-day food diary) energy and carbohydrate intakes at year 4. No other significant associations were noted between acute and daily energy and macronutrient intakes with SQ variables (results not shown).

Lastly, body weight was significantly greater in women with a lower mean SQ, compared to those with a higher mean SQ at 60 min during year 1, according to tertiles (62.9 ± 7.4 vs. 59.7 ± 6.0 kg; $p = 0.02$). No other significant differences in anthropometric/body composition variables were noted between SQ tertiles (data not shown). Changes in body weight were positively correlated with delta fullness SQ at 60 ($r = 0.34$; $p = 0.004$) and 180 ($r = 0.30$; $p = 0.01$) min between years 1 and 5. Similarly, changes in fat mass were positively correlated with delta fullness SQ at 60 min between years 1 and 5 ($r = 0.24$; $p = 0.04$). Conversely, delta fat mass was negatively correlated with delta hunger SQ at 60 ($r = -0.34$; $p = 0.02$) and 180 min ($r = -0.34$; $p = 0.02$), as well as delta PFC SQ at 60 ($r = -0.33$; $p = 0.02$) and 180 ($r = -0.32$; $p = 0.02$) min between years 4 and 5. Changes in waist circumference were negatively associated with delta desire to eat SQ at 60 min ($r = -0.31$; $p = 0.02$), delta hunger SQ at 60 min ($r = -0.32$; $p = 0.02$), delta fullness SQ at 60 ($r = -0.31$; $p = 0.02$) and 180 min ($r = -0.29$; $p = 0.03$), and delta mean SQ at 60 min ($r = -0.32$; $p = 0.02$) between years 3 and 4 only. No other significant correlations were noted between changes in anthropometric parameters and changes in SQ (results not shown).

DISCUSSION

To our knowledge, this is the first study to examine the potential variations in SQ across the menopausal transition, and assess whether changes in SQ are related to changes in body composition variables. Collectively, our findings suggest that most SQ variables were greatest during years 3 and 4 of this 5-year study, although no effect of the menopausal status was noted. Multivariate regression analyses revealed that the SQ explained between 5 and 14% of the variance in energy and macronutrient intakes measured acutely with a buffet meal or with a 7-day food diary. Lastly, variations in body weight and fat mass were positively correlated with changes in fullness SQ between years 1 and 5, while fat mass and waist circumference between years 4 and 5 and years 3 and 4, respectively, were negatively associated with variations in SQ.

A recent study in the same cohort noted overall increases in fasting and area under the curve calculations for desire to eat and hunger ratings, as well as a decrease in fasting fullness ratings across the menopausal transition [3]. Conversely, most SQ variables in the present study were greater during years 3 and 4, compared to baseline (year 1) values. Fasting and post-meal appetite sensations represent an immediate subjective sensation, while the SQ is a derivative of the interaction between the changes in subjective appetite sensations in relation to the energy content of the meal [8], which may in part explain this discrepancy in results. Taken together, the results of the current study suggest that the SQ in response to a standardized meal may be greater during the menopausal transition and/or postmenopausal vs. premenopausal years, and may in part lead to the overall decrease in daily energy, lipid and protein intakes previously reported in this sample [3]. However, no differences in SQ variables were noted between menopausal status groups assessed at years 2 through 5, meaning that these variations occurred across time, independently of menopausal status. As such, it is likely that these variations in SQ may be more related to chronological age rather than to menopausal status. This issue deserves additional consideration.

An increase in fullness, PFC and mean SQ predicted overall decreases in energy and macronutrient intakes at lunch during years 3 and 5, whereas increases in fullness SQ assessed during years 1 and 4 significantly predicted decreases in protein intake only. As for daily (7-day food diary) EI, only PFC and fullness SQ significantly predicted energy and carbohydrate intakes, respectively, during year 4. Although these associations seem consistent, the multivariate regression model suggests that the SQ only explains between 5 and 14% of the variance in lunch and daily energy and macronutrient intakes. This implies that other factors also contribute to this variance in food intake. Similar associations between fullness SQ and EI were previously noted in normal-weight, obese and weight-reduced individuals [7], [8]. Duval and colleagues [3] observed significant increases in fasting and area under the curve calculations for desire to eat and hunger ratings, as well as decreases in fasting fullness ratings across the menopausal transition in the same cohort as in the present study. However, these observed changes in appetite ratings did not coincide with increases in acute (one meal) and daily (7-day food diary) EI. It may thus be suggested that the SQ is a more accurate predictor of acute energy and macronutrient intakes under controlled laboratory conditions. However, the low variance noted in the present study also suggests that other variables that were not measured may be better predictors of feeding. Furthermore, our results suggested that certain SQ variables (i.e. fullness, PFC and mean SQ) may be better predictors of subsequent energy and macronutrient intakes. To our knowledge, only two other studies assessed the link between the different SQ variables and EI, and noted that only fullness SQ significantly predicted subsequent EI during an *ad libitum* lunch [7],[8]. Hence, future studies are needed to further confirm our results.

Lastly, body weight was significantly greater in women with a lower mean SQ, compared to women with a higher mean SQ during year 1, according to tertiles. Changes in fullness SQ were significantly and positively correlated with changes in body weight and fat mass between years 1 and 5. Conversely, changes in the SQ for different appetite ratings were significantly and negatively correlated with changes in fat mass and waist circumference between years 4 and 5, and years 3 and 4, respectively. These novel findings add to those previously reported by Drapeau and colleagues [8] following a weight-loss intervention; observing a significant positive association between the changes in desire to eat SQ and the amount of weight loss (i.e. greater desire to eat SQ was associated with a greater body weight loss) in men, but not women. King and colleagues [19] also noted a significant increase in desire to eat, hunger and fullness SQ following a 12-week exercise intervention in responders (i.e. changes in body composition that were equal to or greater than that expected due to the increase in exercise energy expenditure) and non-responders (i.e. changes in body composition that were less than that expected due to the increase in exercise energy expenditure), thus suggesting that this increase in SQ occurred independently of the changes in body composition. Taken together, our results suggest that greater increases in SQ (or greater overall satiety responses to a meal) may be associated with smaller changes in waist circumference and fat mass in women during the menopausal transition.

However, based on these results alone, we are unable to determine whether changes in SQ lead to changes in fat mass and waist circumference or vice versa. Hence, future studies are needed to clearly establish this potential cause-and-effect relationship.

The present findings are limited to a sample size of normal-weight women, which limits generalizability to other populations. Furthermore, not all participants completed all annual measurements from years 1 to 5 of data collection, meaning that the number of participants included in the different analyses varied from year to year. Only 1-day assessments of SQ were performed annually, which does not account for normal day-to-day variations in this variable. Lastly, the correlations computed between the changes in SQ and the changes in anthropometric parameters cannot infer causality (i.e. it is unknown whether increases in SQ may lead to decreases in fat mass and/or waist circumference or vice versa), and, although statistically significant, the SQ only explains a small portion of the variance in EI.

We observed for the first time increases in most SQ variables in and around the menopausal transition, an effect most likely explained by chronological aging rather than menopausal status *per se*. Furthermore, the SQ seemed to be a consistent predictor of feeding and of changes in body weight and body composition. Future studies should assess the effects of a satiating diet in women during the menopausal transition to evaluate the cause-and-effect relationship between the changes in SQ and body composition/anthropometric parameters.

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