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Sustained satiety induced by food foams is independent of energy content, in healthy adults

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ABSTRACT

Our previous research demonstrated high, sustained satiety effects of stabilized food foams relative to their non-aerated compositions. Here we test if the energy and macronutrients in a stabilized food foam are critical for its previously demonstrated satiating effects. In a randomized, crossover design, 72 healthy subjects consumed 400 mL of each of four foams, one per week over four weeks, 150 min after a standardized breakfast. Appetite ratings were collected for 180 min post-foam. The reference was a normal energy food foam (NEF1, 280 kJ/400 mL) similar to that used in our previous research. This was compared to a very low energy food foam (VLEF, 36 kJ/400 mL) and 2 alternative normal energy foams (NEF2 and NEF3) testing possible effects of compositional differences other than energy (i.e. emulsifier and carbohydrate source). Appetite ratings were quantified as area under the curve (AUC) and time to return to baseline (TTRTB). Equivalence to NEF1 was predefined as the 90% confidence interval of between-treatment differences in AUC being within −5 to +5 mm/min.

All treatments similarly affected appetite ratings, with mean AUC for fullness ranging between 49.1 and 52.4 mm/min. VLEF met the statistical criterion for equivalence to NEF1 for all appetite AUC ratings, but NEF2 and NEF3 did not. For all foams the TTRTB for satiety and fullness were consistently between 150 and 180 min, though values were shortest for NEF2 and especially NEF3 foams for most appetite scales.

In conclusion, the high, sustained satiating effects of these food foams are independent of energy and macronutrient content at the volumes tested.

1. Introduction

There is growing evidence that lowering dietary energy density may be an effective strategy for the prevention and treatment of obesity (Blatt, Williams, Roe, & Rolls, 2012; Ello-Martin, Ledikwe, & Rolls, 2005; Ello-Martin, Roe, Ledikwe, Beach, & Rolls, 2007; Rolls, Bell, & Thorwart, 1999; Welch, 2011). Two strategies to lower the energy density of specific foods are 1) to increase the water content, thereby increasing weight and volume but not energy and 2) to increase the gas content, thereby increasing volume but not weight and energy.

Several studies have shown that water consumed with a meal, or added to a food matrix, such as soup or a milk-based drink increases satiation (Almiron-Roig, Chen, & Drewnowski, 2003; Almiron-Roig, Grathwohl, Green, & Erkner, 2009; Gray, French, Robinson, & Yeomans, 2003; Lappalainen, Mennen, van, & Mykkanen, 1993; Latner, Rosewall, & Chisholm, 2009; Norton, Anderson, & Hetherington, 2006; Rolls et al., 1999). However, water seems not to have sustained effects on satiety (Almiron-Roig et al., 2003, 2009; Lappalainen et al., 1993; Martens & Westerterp-Plantenga, 2012; Rolls et al., 1999).

The effects of incorporation of gas in foods on satiety and energy intakes have also been studied (Cuomo et al., 2011; Moorhead, Livingstone, Dunne, & Welch, 2008; Rolls, Bell, & Waugh, 2000). Rolls et al. have shown that incorporation of air in iso-energetic milkshakes served as preloads 30 min before lunch, significantly

Abbreviations: AUC, area under the curve; AUCtreat, area under the curve for the treatment period; CI, confidence interval; DATEM, diacetyl tartaric acid ester of mono- and diglycerides; eVAS, electronic visual analogue scale; ICH, International Conference on Harmonisation; NEF1, normal-energy food foam 1 [reference foam]; NEF2, normal-energy food foam 2; NEF3, normal-energy food foam 3; PP, per protocol; TTRTB, time to return to baseline; VLEF, very low energy food foam.

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affected appetite and subsequent energy intake (Rolls et al., 2000). In contrast, Cuomo et al. found no effect of carbonation of a pre-meal beverage on food intake immediately thereafter, despite increased gastric volume (Cuomo et al., 2011). Effects on satiety and food intake may depend on the level of carbonation, though, as shown by Moorhead et al. (Moorhead et al., 2008), but these effects seem not to persist after the meal (Moorhead et al., 2008; Rolls et al., 2000). Thus, until recently only small or short-lived satiety effects of added gasses have been shown.

We have recently reported that aeration of a liquid meal replacer, resulting in a stable foam, can dramatically increase satiety for a prolonged time as compared to the non-aerated product with the same composition and energy content (Melnikov et al., 2014). We have furthermore shown these satiating effects for foam volumes ranging from as low as 50–100 ml up to 1000 ml (Melnikov et al., 2014; Murray K et al., 2015; Peters, Koppenol, Schuring, Abrahamse, & Mela, 2015) in a dose-response pattern. Most recently we have shown that gastric distension can largely but not completely explain these effects (Murray K et al., 2015).

We hypothesized that the sustained satiety effect observed with these foams is at least partially mediated through nutrient-dependent mechanisms such as delayed digestion due to layering (creaming) of the foams in the stomach, which in turn can lead to delayed emptying and stimulation of an 'intestinal phase' appetite mechanism (Peters & Mela, 2008; Powley & Phillips, 2004). The foams used in those studies were in part stabilized by their dairy protein content. If delayed digestion of foams plays a substantial role, then the satiating properties of foams would be energy-dependent and perhaps also macronutrient specific, since the top layer of foam will be enriched in proteins, while non-surface active carbohydrates will be equally distributed in the top and bottom layers (Murray K et al., 2015).

The primary objective of this study was therefore to assess if a very low energy foam (VLEF, 36 kJ per 400 ml serving) has the same effect on satiety as the same volume of a reference normal energy foam (NEF1, 280 kJ/400 ml) similar to that used in previous research (Murray K et al., 2015), by testing for equivalence of these two foams. Two other NEFs with slightly different compositions were also compared to the reference foam to test for possible effects of differences in composition (carbohydrate type, emulsifier) other than energy *per se*.

2. Methods

2.1. Subjects

The study was conducted at Eurofins Optimed (Gieres, France) in healthy normal weight and overweight male and female participants aged 18–60 years. Participants were recruited from an existing subject panel and by advertisement. Respondents were first informed verbally about the study before an appointment was scheduled. Before any screening assessment was performed, complete and detailed information about the aim, the consequences and the constraints of the trial was given by a physician, both verbally and by reviewing the information leaflet and consent form. A copy of the information leaflet and consent form was given to subjects.

Respondents gave written informed consent and were accepted for participation if they were in good health (medical history), had a stable body weight for > 6 mo, and had a Body Mass Index (BMI) between 20 and 30 kg/m^2. Subjects were excluded when they reported to be pregnant, lactating or wishing to become pregnant. Smokers, highly restrained eaters (score >14 on the Three Factor Eating Questionnaire (Stunkard & Messick, 1985)), subjects with an apparent eating disorder (score ≥ 2 on SCOFF questionnaire (Garcia et al., 2010; Morgan, Reid, & Lacey, 1999)), and those expressing dislike, allergy or intolerance to study products were excluded from participation. Subjects who were dieting, engaged in intense exercise (>10 h/w) or reporting participation in night-shift work two weeks prior to screening or during the study were also excluded from participation. To increase subject compliance, potential volunteers were asked to taste 150 ml of one of the aerated products during the information session. They were instructed to consume the 150 ml sample and they were shown a 400 ml portion that they would receive in the study. Subjects who felt that they would be unable to consume 400 ml of study product within 10 min were excluded from the study.

Medical ethical approval of this study was given by the Comité de Protection des Personnes Sud-Est III (Ethics Committee) Lyon (France) and the relevant French authority (Agence française de sécurité sanitaire des produits de santé).

2.2. Study products

Detailed compositions of the four foams are given in Table 1. In NEF1, the reference foam similar to that used in our previous research (Murray K et al., 2015), xanthan gum and milk protein (as skim milk powder) were used to stabilize the foam at point of consumption and during oral and gastric passage (Murray K et al., 2015). Formulation of a stable foam with the lowest possible energy content (VLEF) necessitated removing the macronutrients and stabilizing the formulation instead with an appropriate emulsifier (diacetyl tartaric acid ester of mono- and diglycerides, DATEM; Danisco, Du Pont, Dordrecht, The Netherlands). However, theoretically the DATEM itself might affect efficacy, so NEF2 (NEF1 with addition of DATEM) was included as an additional control. Lastly, to test whether the carbohydrate composition was relevant, we included NEF3 in which skimmed milk powder (containing lactose) was replaced by milk protein concentrate and maltodextrin, to give the same total protein and carbohydrate as NEF1 and NEF2. The

Table 1
Foam compositions per 400 ml serving.

	VLEF[a] 118 g	NEF1 125 g	NEF2 124 g	NEF3 124 g
Ingredients (% weight)				
Skim Milk Powder[b] (SMP) (%)	0	15	15	0
Milk Protein Concentrate[c] (MPC) (%)	0	0	0	6.3
DATEM[d] (%)	0.7	0	0.7	0.7
Xanthan gum[e], Keltrol RD (%)	0.5	0.5	0.5	0.5
Maltodextrin[f] (%)	0	0	0	8.8
Erythritol[g] (%)	10	10	10	10
Lemon Flavor[h] (%)	0.1	0.1	0.1	0.1
Water (%)	88.7	74.4	73.7	73.7
Composition				
Total energy (kJ) [kcal]	36 [9]	280 [67]	314 [75]	335 [80]
Total carbohydrates (g)	11.8	22.3	22.2	23.7
Total lactose (g)	0.0	9.8	9.8	0.4
Total dietary fiber (g)	0.6	0.6	0.6	0.6
Total protein (g)	0.0	6.1	6.1	6.2
Total fat (g)	0.8	0.3	1.1	1.0

[a] The VLEF formulation was acidified to pH = 3 by addition of tartaric acid; pH of the NEF2 formulation was 5.9 and pH of the NEF3 and NEF1 formulations were 6.4.
[b] SMP medium heat sweet, Lactoland Trockenmilchwerk GmbH, Dülmen,Germany.
[c] Milk Protein Concentrate, Refit MPC 80, FrieslandCampina Domo, Beilen, the Netherlands.
[d] DATEM 165, Panodan 165, Danisco, Du Pont, Dordrecht, the Netherlands.
[e] Xantan gum, Keltrol RD, CP Kelco, Atlanta, Georgia, USA.
[f] Maltodextrin, MD 20 P, Avebe, Veendam, the Netherlands.
[g] Erythritol, Erylite, Jungbunzlauer GmbH, Pernhofen, Austria.
[h] Lemon flavor 213841, Symrise, Holzminden, Germany.