AMERICAN COLLEGE OF PROSTHODONTISTS
Your smile. Our specialty.

Relationship between Body Fat and Masticatory Function

Alfonso Sánchez-Ayala, PhD,[1] Nara Hellen Campanha, PhD,[2] & Renata Cunha Matheus Rodrigues Garcia, PhD[3]

[1]Assistant Professor, Department of Dentistry, State University of Ponta Grossa, Ponta Grossa, Brazil
[2]Professor, Department of Dentistry, State University of Ponta Grossa, Ponta Grossa, Brazil
[3]Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, State University of Campinas, Piracicaba, Brazil

The article is associated with the American College of Prosthodontists' journal-based continuing education program. It is accompanied by an online continuing education activity worth 1 credit. Please visit www.wileyonlinelearning.com/jopr to complete the activity and earn credit.

Keywords
Occlusal pairs; masticatory performance; swallowing threshold; chewing rate; body mass index.

Correspondence
Renata Cunha Matheus Rodrigues Garcia, Piracicaba Dental School, State University of Campinas—Prosthodontics and Periodontology, A venida Limeira, n° 901, Bairro Areião, Piracicaba, SP, Brazil, CEP: 13414–903. E-mail: regarcia@fop.unicamp.br

The authors deny any conflicts of interest.

Accepted July 28, 2012

doi: 10.1111/j.1532-849X.2012.00937.x

Abstract

Purpose: The aim of this cross-sectional study was to investigate the relationship between body fat and masticatory function.
Materials and Methods: One hundred dentate and partially edentulous participants (33 male; mean age, 39.7 ± 16.6 years) were selected. Body fat was established through body mass index (BMI). Masticatory function was evaluated by quantifying occlusal pairs and determining masticatory efficiency and swallowing threshold with the sieving method. During the swallowing threshold test, chewing rate was registered. Masticatory ability was also evaluated with a 5-point Likert scale questionnaire. Data were analyzed with Spearman and chi-square tests, as well as binary logistic regression analysis for the presence of increased BMI ($\alpha = 0.05$).
Results: Age (rho = 0.517), occlusal pairs (chi-square = 26.353), masticatory efficiency (chi-square = 30.935), masticatory ability (chi-square = 25.132; $p < 0.001$), and swallowing threshold (chi-square = 8.730; $p < 0.005$) were related to BMI. Age (odds ratio, OR = 1.048, 95% CI = 1.008 to 1.089) and lower masticatory efficiency (OR = 4.792, 95% CI = 1.419 to 16.183) were predictive of increased body fat ($p < 0.05$). Gender (chi-square = 0.402, $p = 0.526$) and chewing rate (rho = –0.158, $p = 0.117$) were not related to BMI.
Conclusions: These results suggest that people with lower masticatory efficiency may be at risk for increased body fat.

The prevalence of increased body fat and associated comorbidities, such as type 2 diabetes, cardiovascular disease, and certain cancers, is quickly increasing and represents a major threat to public health worldwide, even in Latin America.[1] Besides the influence of genetically predetermined metabolic and endocrine factors,[2] increased body fat results from a long-term positive energy balance in which the energy intake from food is larger than the energy expenditure.[3]

Food intake can be influenced by food texture, which involves a sensory perception response to physical stimuli resulting from contact among teeth, oral soft tissue, and food during mastication.[4] The importance of texture in the acceptability of food varies widely depending on its consistency.[5] People with a compromised dental status may avoid hard-to-chew foods and instead choose processed foods, favoring the absorption of cholesterol and saturated fatty acids,[6] or may prefer simple carbohydrate-rich diets that are high in calories but low in dietary fiber, vitamins, and protein, thus leading to weight gain.[7] In addition, they may increase cooking times to soften foods, degrading essential nutrients and decreasing their bioavailability.[6]

A decreased number of teeth and conventional denture wearing have been associated with inadequate dietary habits,[8] as well as altered anthropometric measures, inappropriate blood nutrient concentration,[9] and increased body mass index (BMI) in the elderly.[10] In adults, the intake of nonstarch polysaccharides from whole meal breads, cereals, vegetables, and fruits was higher in dentate than complete denture wearers.[11] In one study, participants with fewer than 28 teeth had a lower intake of carrots, tossed salads, and dietary fiber, and lower serum levels of beta carotene, folate, and vitamin C than dentate participants.[12] Although other environmental factors could contribute to variations in body fat, BMI is associated with number of teeth, even when socioeconomic, dietary, psychological, lifestyle, and comorbidity factors are considered.[13,14] Moreover, morbidly obese dentate patients scheduled for bariatric surgery showed higher masticatory time and number of masticatory cycles before swallowing, and lower masticatory performance than nonobese controls.[15] However, disregarding the occlusal factors but including the control of gender, presence of binge-eating disorder, motivation (food deprivation and preferences), and size and shape of the ingested food, no underlying disturbance in obese patients was suggested in the control of eating behavior exerted by the physical properties of food.[16]

Therefore, to determine the influence of masticatory function on body fat, occlusal and comminution factors should be simultaneously assessed in patients of different ages; however, few reports exist on this topic, probably because these factors are time-consuming to assess and require specific laboratory equipment.[7] Because the static comminution capacity can be overestimated when counting only the number of teeth, the occlusal factor should be evaluated through the number of occlusal pairs or antagonist teeth, which involve the real number of functional teeth.[17] The comminution factor should be evaluated through masticatory efficiency and swallowing threshold measurements, which characterize the dynamic comminution capacity of patients.[15,18] During the evaluation of swallowing threshold, the chewing rate can also be measured, and its variation may indicate a compensatory mechanism for impaired masticatory function.[18] Furthermore, people do not necessarily adjust their dietary intake behavior because of poor occlusal state or comminution capacity because their preferences also depend on their feelings about certain foods, which is defined as masticatory ability.[5,18]

Thus, the purpose of this study was to verify the relationship between body fat and the simultaneously assessed number of occlusal pairs, masticatory efficiency, swallowing threshold, chewing rate, and masticatory ability.

Materials and methods

A convenience sample of 100 participants (33 male, mean age 39.7 ± 16.6 years) was selected from among patients of Cayetano Heredia University Dental Clinic, San Martin de Porres. This suburban district is located on the periphery of Lima on the Peruvian Pacific coast. Patients were considered for inclusion if they presented good general health, complete or partial dentition, or had received oral rehabilitation with conventional fixed partial dentures. Exclusion criteria included the presence of systemic diseases, pregnancy, diet regime, use of medications affecting metabolism and/or appetite, xerostomy, orofacial or dental pain, moderate or severe periodontal disease, and rehabilitation with implant-supported or conventional removable dentures. The ethnicity and regional characteristics (mestizo Spanish/South American Native) were homogeneous and typical of this community. The research was conducted according to the Caytano Heredia University Dental Clinic, San Martin de Porres ethics committee, and written consent was obtained from all participants.

Body mass index

To determine body fat, patients were weighed on a scale arm bascule (Adam Equipment Co., Milton Keynes, UK) to the nearest 0.1 kg and measured with a stadiometer (Adam Equipment Co.) to the nearest 0.1 cm. Patients were evaluated with both feet together, without shoes, and with the Frankfort plane parallel to the ground. BMI values were calculated by dividing weight (kg) by the square of the height (m^2).[10] According to the World Health Organization, the BMI cut-off to determine normal and increased BMI categories was established at 25.0 kg/m^2 (http://apps.who.int/bmi/index.jsp). Participants with increased BMI in this study included those who were overweight or mildly obese.

Number of occlusal pairs

The number of occlusal pairs was determined clinically by counting antagonist teeth in occlusion. Doubts about contact were clarified by visual inspection of master casts made of type III dental stone and related in maximum intercuspal position using a nonarcon semi-adjustable articulator. Patients were categorized into three groups according to their number of occlusal pairs: (1) 0 to 4, (2) 5 to 9, or (3) 10 to 14.

Masticatory efficiency

Patients chewed artificial test food processed using silicone rubber (Optosil Plus®, Heraeus Kulzer, Hanau, Germany). The material was manipulated according to the manufacturer's instructions and prepared in molds to form cylinders (20 mm diameter, 5 mm high, with a weight of approximately 2.5 g).[19] Cylinders were stored for up to 5 days at room temperature. Each patient received a portion of two cylinders weighing approximately 5 g, and they were instructed to chew in their habitual way. After 20 chewing cycles counted by the examiner, the particles were expectorated into a beaker, and the mouth was rinsed with 200 ml of water, which was expectorated into the same container.[19] Comminuted particles were rinsed with 200 ml of water and dried in an oven (Odontobrás EL-1.1, Ribeirão Preto, Brazil) at 80°C for 25 minutes. Dried particles were placed into sieves with openings of 2.8 mm and 1.4 mm and vibrated for 120 seconds. The test material retained in each sieve was collected and weighed on an analytical balance reading to 0.1 g (8027–200, Soehnle, Oberboihingen, Baden-Wurttemberg, Germany). The equation $ME = 100\ [1 - (X + Y)/(2T - X)]$ was used to determine masticatory efficiency (ME), where X and Y are the weight of the retained particles in the first and second sieves, respectively, and T is the total weight of the particles after mastication.[19] Because the results were relative to the nature of the test food and ME calculus, Lepley et al[20] employed a median value for the entire sample as a mathematical artifice to divide poorer from better masticators. Then, if the percentage of masticatory efficiency was $>$ or $\leq$ 9.1%, each patient was categorized as a better or poorer performer, respectively.

Swallowing threshold and chewing rate

The swallowing threshold was determined by having participants chew another two test food cylinders. When patients had an imminent sensation of swallowing, they were told to expectorate the particles into a beaker, rinse their mouth with 200 ml of water, and expectorate this water into the same container. Comminuted particles were processed as described for the masticatory efficiency test. The swallowing threshold was defined as the weight percentage of particles that could pass through a 1.4 mm sieve.[17] For each participant, if the swallowing threshold was $>$ or $\leq$ 9.5% (median value for the entire sample), then the participant was defined as a better

Table 1 Frequency of categorical and continuous variables according to BMI conditions (n = 100)

	Normal BMI (n = 44)		Increased BMI (n = 56)		Statistical	
Categorical variables	n	%	n	%	Chi-square value	*p* Value
Gender					0.402	0.526
Female	28	63.6	39	69.6		
Male	16	36.4	17	30.4		
Occlusal status						
0 to 4 occlusal pairs	5	11.4	20	35.7	26.353	<0.001
5 to 9 occlusal pairs	7	15.9	24	42.9		
10 to 14 occlusal pairs	32	72.7	12	21.4*		
Masticatory performance					30.935	<0.001
≤9.1%—poorer	10	22.7	44	78.6		
>9.1%—better	34	77.3	12	21.4*		
Swallowing threshold					8.730	0.003
≤9.5%—poorer	16	36.4	37	66.1		
>9.5%—better	28	63.6	19	33.9*		
Continuous variables	Mean	SD	Mean	SD	Rho value	*p* Value
Age	29.6	15.1	47.7	13.1	0.517	<0.001
Number of masticatory cycles	49.2	23.3	74.7	51.6	0.358	<0.001
Masticatory time	37.0	20.2	58.0	41.9	0.358	<0.001
Chewing rate	83.5	15.5	79.7	14.9	−0.158	0.117

*Significant difference compared to other categories.

or poorer performer, respectively. The number of masticatory cycles necessary and the masticatory time until imminent swallowing were recorded,[15] and the chewing rate was defined as the number of masticatory cycles performed per minute.[18]

Masticatory ability

Patients completed a stage-type 1 to 5 point Likert questionnaire (very poor, poor, acceptable, good, very good) regarding their masticatory ability.[8] On this questionnaire, the patient subjectively rated how difficult it was to crush food in general and for certain foods. Masticatory ability was defined as the median value of all scores for each question. For each patient, if the masticatory ability was > or ≤ 3.5 (median value for the entire sample), then the patient was classified as a better or poorer performer, respectively.

Statistical analysis

Data were explored using IBM® SPSS® Statistics 20 software (IBM Corporation, Armonk, NY), and all statistical inferences were performed with 2-tailed trials assuming a 5% significance level. The frequency of patients in each category of variables was determined for normal and increased BMI conditions. A chi-square test was conducted to associate the categories of gender, occlusal pairs, masticatory efficiency, and swallowing threshold with BMI. To compare occlusal pair categories, the chi-square test was adjusted for all pairwise comparisons within a row of each innermost sub-table by using the Bonferroni correction. Numerical variables (age, number of masticatory cycles, masticatory time, and chewing rate) were related to BMI by applying the Spearman correlation test (rho). Binary logistic regression analysis was used to evaluate the influence of variables on the presence of increased BMI. Initially, the Enter method was applied to analyze all variables in a block entered in a single step. Backward stepwise selection was then performed based on the probability of the Wald statistic. At each step, the least significant variable was removed from the model until all the remaining variables had a statistically significant contribution to the model.

Results

Patient characteristics and masticatory function data are presented in Table 1. Association was found between BMI and number of occlusal pairs. In this case, the proportion of patients with increased BMI was higher when they presented <10 occlusal pairs ($p < 0.05$). Masticatory efficiency and swallowing threshold were also associated with BMI. A greater proportion of patients with increased BMI had masticatory efficiency ≤9.1% and swallowing threshold ≤ 9.5%.

Correlations ($p < 0.001$) were also found between BMI and age, number of masticatory cycles, and masticatory time. For each BMI condition, the proportion of patients in each gender and chewing rate values were similar (Table 1).

Frequencies of masticatory ability scores are shown in Table 2. The proportion of patients presenting increased BMI and masticatory ability ≤3.5 was higher, showing association.

Binary logistic regression analysis using the Enter method showed that any variable influenced ($p > 0.05$) the BMI condition (Table 3); however, after performing the Backward stepwise method, only masticatory efficiency and age could predict ($p < 0.05$) the presence of increased BMI (Table 4).

Table 2 Frequencies of masticatory ability scores according to BMI values (n = 100)

	Normal BMI (n = 44)					Increased BMI (n = 56)				
	1	2	3	4	5	1	2	3	4	5
General	3	6	5	22	8	9	18	23	4	2
Specific foods										
Fresh cheese	0	1	6	12	25	2	3	10	38	3
Cooked fish	0	4	6	8	26	3	4	15	33	1
Steak	7	2	11	20	4	18	19	15	4	0
Sausages	0	5	4	19	16	3	2	13	36	2
Boiled beans	0	0	9	13	22	3	1	8	42	2
Fresh apples	6	4	4	18	12	15	15	20	3	3
Bananas	0	1	6	11	26	2	1	5	46	2
Pastas	0	2	6	15	21	2	1	15	35	3
French bread	4	2	4	20	14	9	9	25	12	1
Cooked chicken	1	5	5	17	16	7	9	28	11	1
Raw vegetables	5	4	6	17	12	13	19	17	5	2
≤3.5—poorer	10 (19.6%)					41 (80.4%)				
>3.5—better	34 (69.4%)					15 (30.6%)*				

*Chi square = 25.132.
$p < 0.001$.

Patients with a masticatory efficiency ≤9.1% presented a risk of increased BMI. In addition, increased age was a weak but significant risk factor to increased BMI. This model showed specificity (capacity to classify participants in the normal BMI category) of 75.0% and sensibility (ability to recognize participants with increased BMI) of 85.7%, presenting an overall correct classification rate of 81.0%.

Discussion

This study was an attempt to determine whether increased BMI is related to masticatory function. The proportion of participants presenting BMI >25 kg/m^2 was higher for participants presenting 5 to 9 and 0 to 4 occlusal pairs. These results are consistent with Forslund et al,[13] who found that BMI is an independent predictor of the number of teeth in middle-aged women, even when socioeconomic, dietary, and psychological factors are considered. Our results are also in agreement with Ostberg et al,[14] who determined an association between tooth loss and obesity in adults aged 30 to 60 years, independent of age, gender, and differences in socioeconomics, lifestyle, and comorbidity. Moreover, comparisons between our results and those from studies on older populations[7,10] showed the number of teeth was also associated with BMI variation.

As previously mentioned, this relationship could be explained by the deprivation of an adequate and varied diet,[6,7] mainly for patients presenting a few and poorly distributed teeth.[10] However, contrary to the present data, risk studies on older populations found that patients with no posterior occlusal pairs[10] and 1 to 8 teeth[21] were almost three times more prone to be obese than lean. The absence of significant risk in our study may be justified by the probable adaptive capacity of patients, because tooth loss can be compensated through improvement in handling bolus, which is regulated by the proprioceptive information encoded from the tongue, lips, and cheeks.[18]

The percentage of patients with increased BMI, poorer masticatory efficiency, and swallowing threshold was higher. Binary logistic regression analysis showed that masticatory efficiency could predict the presence of increased BMI. These data are consistent with Ikebe et al,[7] who found that occlusal force and masticatory performance rather than the number of teeth or type of edentulism, may play an important role in maintaining a normal BMI in older subjects. Veyrune et al[15] also determined that participants with morbid obesity (BMI = 49.1 ± 7.2) showed a lower swallowing threshold for natural foods, such as carrots and peanuts, and a higher number of masticatory cycles and masticatory time to swallow apples, sweet jelly, carrots, and peanuts, as they were unable to adapt to the different food textures. Seemingly, the association of comminuting capacity with BMI can probably be explained through the difficultly in crushing hard-textured fibrous foods.[6,7] On the other hand,

Table 3 Logistic regression model for increased BMI by Enter method (n = 100)

Explanatory variables	B	SE	*p* Value	Odds ratio	95% confidence interval
Age*	0.040	0.028	0.148	1.041	0.986-1.099
Gender	0.154	0.667	0.817	1.167	0.316-4.312
Occlusal status					
10-14 occlusal pairs	—	—	0.794	1	—
5-9 occlusal pairs	0.363	0.990	0.714	1.438	0.207-10.006
0-4 occlusal pairs	0.568	0.846	0.502	1.764	0.336-9.269
≤9.1%—poorer masticatory performance	1.453	0.987	0.141	4.277	0.618-29.584
≤9.5%—poorer swallowing threshold	−0.384	0.758	0.613	0.681	0.154-3.010
Number of masticatory strokes*	0.027	0.040	0.494	1.027	0.951-1.110
Masticatory time*	−0.032	0.050	0.525	0.969	0.879-1.068
Chewing rate*	−0.019	0.035	0.589	0.981	0.917-1.050
Poorer masticatory ability	0.093	0.856	0.914	1.097	0.205-5.879
Constant	−0.922	3.138	0.769	0.398	—

*Continuous variable.
B = partial regression coefficient; SE = standard error.

Table 4 Logistic regression model for increased BMI by Backward Wald method (n = 100)

Explanatory variables	B	SE	*p* Value	Odds ratio	95% confidence interval
≤9.1%—lower masticatory performance	1.567	0.621	0.012	4.792	1.419-16.183
Age*	0.047	0.020	0.017	1.048	1.008-1.089
Constant	−2.386	0.680	<0.001	0.092	—

*Continuous variable.

B = partial regression coefficient; SE = standard error.

Frecka et al[22] did not find differences in the swallowing threshold of almonds between lean and obese (BMI = 34.3 ± 0.6) patients, and Murakami et al[23] found no association between dietary hardness and BMI variation.

Nevertheless, food intake regulation also involves various central and peripheral mechanisms, where the cephalic phase of digestion plays a fundamental role.[24] The cephalic phase is comprised of a set of physiological, endocrine, and autonomous responses of the digestive system derived from the stimulation of the sensory systems in the oropharyngeal cavity.[24] Then, the influence of masticatory efficiency on BMI may also be a result of muscular activity exerted during mastication, which according to Sakata et al[25] is a potent input signal to activate histamine neurons and improve the satiety mechanism at the mesencephalic trigeminal sensory nucleus in rats. Not only muscular effort, but also greater oral sensory exposure to food by eating using small bite sizes and increased masticatory time can reduce food intake in adults with normal BMI.[26] Sensory stimulation through a higher number of masticatory cycles may also promote the release of enteroendocrine peptides (appetitive hormones), such as insulin, ghrelin, cholecystokinin, peptide YY, and glucagon-like peptide-1.[27]

Although the number of masticatory cycles and time before swallowing showed positive correlations with BMI, the chewing rate was similar to participants with normal and increased BMI. This result agrees with Karl et al,[28] who concluded that the rate at which food is consumed (duration of meals and not the chewing rate per se) by obese and lean participants does not appear to alter satiety despite a small effect on some appetitive hormonal responses. Although this issue is inconclusive, bariatric surgery candidates with severe obesity are advised to control feeding behavior and to eat less food more slowly,[15,29] and oral rehabilitation is advised for patients with fewer than 7 to 8 occlusal pairs.[15]

With regard to masticatory ability, the fraction of participants with increased BMI and poorer masticatory ability was higher than for participants with better ability, indicating that participants with impaired masticatory function may impose certain dietary restrictions upon themselves according to their masticatory ability.[6,8] Although participants with increased BMI presented more difficulty in chewing all foods, this difficulty was more evident with hard foods, such as steak, raw vegetables, and fresh apples (Table 2). Meat is tough because it is constructed from filaments of myosin and fibrous actin supported on elastic fibers of titin, and organized in bundles. Fresh fruits and raw vegetables are difficult to chew because they contain an intracellular, semipermeable membrane that maintains a higher-than-atmospheric internal pressure from water loading. During fractures, rapid crack propagation through the cells occur, but the fracture rates are slower because the overall structure is more viscoelastic.[5]

BMI is known to be independent of age and gender (http://apps.who.int/bmi/index.jsp); however, in this study, age was correlated to BMI values and was predictive of increased BMI. This result could be explained by the fact that the oral changes, which may alter the diet as mentioned above, are age-related. The texture perception of food also changes with age in that more foods are recognized as being hard to chew.[30] Comminution capacity is also decreased in older patients because of the loss of functional postcanine teeth, lower occlusal force and salivary flow, and higher number of masticatory cycles and electromyography activity per sequence.[31]

Reducing the incidence of increased body fat requires coordination among primary health care providers.[32] Because body fat may be associated with masticatory function, it requires multidisciplinary management. Dentists with an elementary knowledge of nutrition may be able to recognize patients who are at risk of developing increased BMI. Educating dentists about obesity and counseling may reduce barriers for those interested in addressing obesity in their practices.[32] Dentists may develop models of intervention not only for bariatric surgery candidates but also for potential obese patients with impaired masticatory function. The public health benefits gained could perhaps justify prosthodontic treatments not covered by social dental insurance programs and health promotion strategies.

Further research is necessary to determine the relationship between nutritional status and masticatory function at more specific age stages, controlling for levels of physical activity. Performing additional methods to investigate the psychological and behavioral changes that lead people, regardless of their educational level or socioeconomic status, to change their diet because of poor masticatory function is also required.

Conclusion

Results from this study indicate that body fat is related to masticatory function; therefore, masticatory efficiency and age may influence BMI.

References

1. Perel P, Casas JP, Ortiz Z, et al: Noncommunicable diseases and injuries in Latin America and the Caribbean: time for action. PLoS Med 2006;3:1448-1451
2. Ramachandrappa S, Farooqi IS: Genetic approaches to understanding human obesity. J Clin Invest 2011;121:2080-2086
3. Bautista LE, Casas JP, Herrera VM, et al: The Latin American Consortium of Studies in Obesity (LASO). Obes Rev 2009;10:364-370
4. Foster KD, Grigor JM, Cheong JN, et al: The role of oral processing in dynamic sensory perception. J Food Sci 2011;76:R49-61

5. Bourne MC: Body–texture interactions. In Bourne MC (ed): Food Texture and Viscosity. Concept and Measurements, Vol 1 (ed 2). San Diego, Elsevier Science, 2002, pp. 33-58
6. N'Gom PI, Woda A: Influence of impaired mastication on nutrition. J Prosthet Dent 2002;87:667-673
7. Ikebe K, Matsuda K, Morii K, et al: The relationship between oral function and body mass index among independently living older Japanese people. Int J Prosthodont 2006;19:539-546
8. Tsai AC, Chang TL: Association of dental prosthetic condition with food consumption and the risk of malnutrition and follow-up 4-year mortality risk in elderly Taiwanese. J Nutr Health Aging 2011;15:265-270
9. Nowjack-Raymer RE, Sheiham A: Association of edentulism and diet and nutrition in US adults. J Dent Res 2003;82: 123-126
10. Sheiham A, Steele JG, Marcenes W, et al: The relationship between oral health status and Body Mass Index among older people: a national survey of older people in Great Britain. Br Dent J 2002;192:703-706
11. Moynihan PJ, Snow S, Jepson NJ, et al: Intake of non-starch polysaccharide (dietary fibre) in edentulous and dentate persons: an observational study. Br Dent J 1994;177:243-247
12. Nowjack-Raymer RE, Sheiham A: Numbers of natural teeth, diet, and nutritional status in US adults. J Dent Res 2007;86:1171-1175
13. Forslund HB, Lindroos AK, Blomkvist K, et al: Number of teeth, body mass index, and dental anxiety in middle-aged Swedish women. Acta Odontol Scand 2002;60:346-352
14. Ostberg AL, Nyholm M, Gullberg B, et al: Tooth loss and obesity in a defined Swedish population. Scand J Public Health 2009;37:427-433
15. Veyrune JL, Miller CC, Czernichow S, et al: Impact of morbid obesity on chewing ability. Obes Surg. 2008;18:1467-1472
16. Spiegel TA: Rate of intake, bites, and chews-the interpretation of lean-obese differences. Neurosci Biobehav Rev 2000;24: 229-237
17. Lucas PW: The evolution of the mammalian dentition. In Lucas PW (ed): Dental Functional Morphology: How Teeth Work, Vol 1 (ed 1). Cambridge, UK,: Cambridge University Press, 2004, pp. 202-256
18. Van Der Bilt A: Assessment of mastication with implications for oral rehabilitation: a review. J Oral Rehabil 2011;38: 754-780
19. Edlund J, Lamm CJ: Masticatory efficiency. J Oral Rehabil 1980;7:123-130
20. Lepley C, Throckmorton G, Parker S, et al: Masticatory performance and chewing cycle kinematics-are they related? Angle Orthod 2010;80:295-301
21. Hilgert JB, Hugo FN, de Sousa Mda L, et al: Oral status and its association with obesity in Southern Brazilian older people. Gerodontology 2009;26:46-52
22. Frecka JM, Hollis JH, Mattes RD: Effects of appetite, BMI, food form and flavor on mastication: almonds as a test food. Eur J Clin Nutr 2008;62:1231-1238
23. Murakami K, Sasaki S, Takahashi Y, et al: Hardness (difficulty of chewing) of the habitual diet in relation to body mass index and waist circumference in free-living Japanese women aged 18–22 y. Am J Clin Nutr 2007;86:206-213
24. Power ML, Schulkin J: Anticipatory physiological regulation in feeding biology: cephalic phase responses. Appetite 2008;50:194-206
25. Sakata T, Yoshimatsu H, Masaki T, et al: Anti-obesity actions of mastication driven by histamine neurons in rats. Exp Biol Med (Maywood) 2003;228:1106-1110
26. Zijlstra N, de Wijk RA, Mars M, et al: Effect of bite size and oral processing time of a semisolid food on satiation. Am J Clin Nutr 2009;90:269-275
27. Cassady BA, Hollis JH, Fulford AD, et al: Mastication of almonds: effects of lipid bioaccessibility, appetite, and hormone response. Am J Clin Nutr 2009;89:794-800
28. Karl JP, Young AJ, Montain SJ: Eating rate during a fixed-portion meal does not affect postprandial appetite and gut peptides or energy intake during a subsequent meal. Physiol Behav 2011;102:524-531
29. Godlewski AE, Veyrune JL, Nicolas E, et al: Effect of dental status on changes in mastication in patients with obesity following bariatric surgery. PLoS One 2011;6:1-7
30. Mioche L, Bourdiol P, Peyron MA: Influence of age on mastication: effects on eating behaviour. Nutr Res Rev 2004;17:43-54
31. Woda A, Foster K, Mishellany A, et al: Adaptation of healthy mastication to factors pertaining to the individual or to the food. Physiol Behav 2006;89:28-35
32. Curran AE, Caplan DJ, Lee JY, et al: Dentists' attitudes about their role in addressing obesity in patients: a national survey. J Am Dent Assoc 2010;141:1307-1316