Association between underweight and taste sensitivity in middle- to old-aged nursing home residents in Sri Lanka: a cross-sectional study

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Abstract

Low taste sensitivity may be one factor related to undernutrition, which is a major problem in developing countries. The purpose of this cross-sectional study was to examine the association between underweight, one indicator of undernutrition, and taste sensitivity in middle- to old-aged Sri Lankan nursing home residents. Participants were 946 residents with BMI of <25.0 from 25 nursing homes. Data was obtained on height, weight, taste sensitivity, subjective taste ability, sex, age, ethnicity, number of years in nursing homes, activities of daily living (ADL), frequency of exercise, bowel movements, smoking status, drinking status, current number of chronic diseases, number and kinds of medications used, self-reporting questionnaire 20 (SRQ20), subjective smell ability, number of teeth present, Eichner index and flow of saliva. Low sensitivity to bitter taste, being male, old age, low ADL, smoking experience, drinking experience, fewer medications used and use of medication for hypertension and diabetes were each associated with underweight ($P<0.05$). In a multilevel Poisson regression model adjusted for sex, age, ADL, smoking status, drinking status, number of medications used, use of medication for hypertension and diabetes and flow rate of saliva, subjects with low sensitivity (>0.003% quinine hydrochloride dihydrate) to bitter taste had a significant 1.70 times higher prevalence ratio (95% confident interval 1.04-2.80) for underweight compared to those with high sensitivity (0.0001% quinine hydrochloride dihydrate). These results suggest that low taste sensitivity to bitter taste may be one factor related to underweight.

Introduction

The global population is aging, and undernutrition among older people is a global crisis. In Asia, underweight (body mass index [BMI] <18.5), one of the indicators for undernutrition, is associated with a substantially increased risk of death (1). A Food and Agriculture Organization (FAO) report in 2010-2012 estimated that the Asia-Pacific region was home to 528 million of the world's 868 million undernourished people, representing almost no change in the absolute number of undernourished people in 20 years (2).

Factors causing undernutrition can be broadly divided into two main groups (3): a lack of food availability, and a reduced intake when food is available. The former can be the result of inadequate resources (finances etc.), poor access to shops, physical disabilities affecting food preparation, and loneliness or other psychosocial factors (3). The latter can be the result of old age (4,5), impaired physical function (5) and difficulties in chewing, swallowing and poor appetite (3,5).

Poor appetite is one candidate for causing undernutrition because it reduces the pleasure of eating and can thereby contribute to decreased body weight. Cross-sectional studies in Canada (6) and Belgium (7) have shown an association between poor appetite and undernutrition. A longitudinal study in the Netherlands showed that poor appetite is an early determinant of incident undernutrition (8). However, few studies have been conducted in developing countries that have a larger malnourished population than developed countries.

Poor appetite may be ascribed to impaired taste sensitivity. However, the association between undernutrition and sensitivity to the four taste qualities (sweet, salty, sour and bitter) is largely unknown. Many studies have focused on the association between obesity and taste sensitivity, with a specific emphasis on sweet taste (9).

Results from studies on the association between taste perception or taste sensitivity and undernutrition are limited and inconclusive. A cross-sectional study on 89 independently living older people and 67 institutionalized older people in the Netherlands showed no significant association between taste perception and BMI (10). On the other hand, another cross-sectional study in the U.S. on 46 men with chronic obstructive pulmonary disease showed that underweight subjects had a significantly higher bitter taste threshold than normal-weight subjects (11). It is difficult to generalize the results of these studies, as the sample size was small and participants were not community-dwelling people. Moreover, it is unknown whether the results from these studies in developed countries could be

applied to developing countries, because the prevalence of undernutrition and culture that may affect factors related to undernutrition differ.

The purpose of this study was to determine the association between underweight and taste sensitivity using a large sample of middle- to old-aged nursing home residents in Sri Lanka. Although various indicators are used to assess nutritional status, BMI was used in the present study because it "is highly correlated to lean soft-tissue mass, appendicular skeletal muscle mass, and body cell mass indexes" (12), and because it is minimally invasive and thus suitable for evaluating a large sample.

Materials and methods

Participants

This cross sectional study was conducted from July, 2010 to August, 2011. Twenty-five facilities having 25 or more residents and located in three districts (Colombo, Gampaha and Kaltutara) of Western Province, Sri Lanka, were randomly selected from 97 nursing homes registered with the Social Service Department of Western Province. The facilities are funded by combinations of governmental subsidies, private donations and pensions, and are administered by a non-government organization (NGO).

A total of 1,062 (78.1%) out of 1,360 residents, aged 50-96 years, from the 25 nursing homes participated in the present study. After excluding 46 subjects with missing data on height and/or weight, 5 with missing data on other variables used in this study, and 65 with BMI ≥25.0 kg/m^2, the remaining data from 946 subjects (383 males and 563 females) was used for analyses.

This study was conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki, and was approved by the ethical review committee of Sri Lanka Medical Association. Written informed consent was obtained from all participants.

Outcome variables

The height and weight of all residents were measured and BMI was calculated as the weight divided by the square of the height (kilograms per square meter). Subjects were categorized into two groups according to the following BMI categories: <18.5 (underweight) and 18.5–24.9 (normal weight) (13, 14).

Taste sensitivity test and subjective taste ability

Taste sensitivity was assessed using the whole-mouth method (15) by two dentists on the basis of a

manual for the taste sensitivity test prepared by NY, GK and TY. Five taste qualities (sweet, salty, sour, bitter and umami) were assessed with one compound per taste, and each compound was presented at four different concentrations, except for umami (one concentration). The test consisted of aqueous solutions of sucrose (0.3, 1.0, 3.0, and 10.0 % (w/w)), sodium chloride (0.1, 0.3, 1.0, and 3.0 % (w/w)), sodium citrate (0.01, 0.03, 0.1, and 0.3 % (w/w)), quinine hydrochloride dihydrate (0.0001, 0.0003, 0.001, and 0.003 % (w/w)) and monosodium glutamate (0.1 % (w/w)). For each solution, subjects rinsed their mouth with the whole sample (5 ml) to evaluate the taste and then spit it out. Each subject was asked to identify whether a taste sensation was present and, if so, on the nature of the taste. They rinsed their mouth with distilled water before another taste was tested, but not before testing the next higher concentration of the same taste solution. Detection threshold, i.e., concentration for absolute threshold of taste sensation, and whether or not the four kinds of tastes (sweet, salty, sour and bitter) were correctly identified were recorded.

Subjective taste ability was ascertained by asking, “How is your ability to taste food?” with possible answers of “no problem”, “cannot taste well” or “can hardly taste at all”. Poor appetite was ascertained by asking, “Is your appetite poor?” in self-reporting questionnaire 20 (SRQ20), with possible answers of “yes” or “no”.

Covariates

Data of sex, age, ethnicity, number of years in nursing homes, activities of daily living (ADL), frequency of exercise, bowel movements, smoking status, drinking status, current number of chronic diseases, number and kinds of medications used, SRQ20, and subjective smell ability were obtained from a self-reporting questionnaire or residents’ records from the facilities. To evaluate ADL, we ranked subjects according to the six levels of long-term care need (LTCN) (16), which is a target index drawn up in 1997 by the Ministry of Health and Welfare, Japan. Subjects were classified by described condition and required care. Number of different chronic diseases from among hypertension, cardiac disease, stroke, diabetes mellitus, respiratory disease (asthma, chronic bronchitis or pulmonary emphysema), rheumatoid arthritis, and cancer was recorded. The accuracy of self-reports on selected data of chronic diseases was shown to be adequate (17). The number of different medications taken regularly, including prescription and non-prescription medications, over-the-counter medications and vitamins, was recorded. Medications that were used by at least 5% of the study subjects were selected

for examining kinds of medication. These were medicines for hypertension (37.2%), cardiovascular diseases (17.8%), diabetes (15.0%), asthma (8.4%) and mental disorders (8.0%), and vitamins (15.6%).

Depression and anxiety in the participants was assessed using the SRQ20, a screening tool for common mental disorders (CMD) designed by WHO for use in developing countries (18, 19). Respondents were asked 20 yes/no questions relating to symptoms of depression and anxiety with a reference period of the previous 30 days. As the validation usually suggested a cut-off of 7/8 to separate probable non-cases from cases of CMD, this cutoff was used in this study (20).

The number of teeth present and Eichner classification were recorded by two dentists and classified into four (0, 1<9, 10<19, 20 or more) and three (groups A, B and C) categories, respectively.

Oral dryness was monitored using Saxon tests (21). Salivary flow was examined for 2 minutes by weighing a cotton roll.

Analysis

Data from past and current smokers was combined due to the small number of respondents in the current smokers' category (3.1%). Similarly, data from past and current drinkers was combined due to the small number of respondents in the current drinkers category (1.7%). Associations of underweight defined by BMI <18.5 with taste sensitivity to the five taste qualities, subjective taste ability, and each covariate were analyzed. Poisson regression models were used to calculate the prevalence ratios (PRs) and 95% confidence intervals (CIs) for underweight.

First, univariate PRs were calculated for each taste variable and each covariate. Variables that were significant ($P<0.05$) or marginally significant ($0.05 \leq P<0.06$) in the univariate analysis were selected as covariates for subsequent multilevel Poisson regression models with random intercepts and fixed slopes to calculate bivariate multilevel PRs taking into account variations in the outcomes between facilities (22). In model 1, sex, age, ADL, and smoking and alcohol status were added to the univariate model. In model 2, number and kinds (hypertension and diabetes) of medications used were added to model 1. In model 3, flow rate of saliva was added to model 2.

To further examine the possible pathway from taste sensitivity to underweight, the association between taste sensitivity, which was significantly associated with underweight, and poor appetite was analyzed using a Chi-square test. All statistical analyses were conducted using IBM SPSS Statistics

version 19 (IBM Co., Armonk, NY, USA) and MLwiN 2.20 software package (Centre for Multilevel Modelling, University of Bristol, Bristol, UK).

Results

BMI ranged from 11.4 to 25.0, and the mean and standard deviation were 19.1 and 2.8, respectively. A total of 393 (41.5%) out of the 946 residents were underweight. Rates of underweight in each facility ranged from 23.1% to 77.3% and the difference in rates among the 25 facilities was statistically significant (P<0.001, Chi-square test).

Table 1 shows the rates of underweight and bivariate PRs for underweight according to taste variables and covariates. Low sensitivity to bitter taste, being male, old age, low ADL, smoking experience, drinking experience, fewer medications used, use of medicine for hypertension and use of medicine for diabetes were each associated with underweight (P<0.05). No significant associations were observed between underweight and sensitivities to sweet, salty, sour and umami tastes, or subjective taste ability.

Table 2 shows the results of multilevel Poisson regression analyses. In the fully adjusted model 3, subjects with a low sensitivity (>0.003% quinine hydrochloride dihydrate) to bitter taste had a significant 1.70 times higher PR (95% CI 1.04-2.80) for underweight compared to those with a high sensitivity (0.0001% quinine hydrochloride dihydrate). Adding number and kinds of medications (from model 1 to model 2) did not affect the PR of sensitivity to bitter taste, but adding flow rate of saliva (from model 2 to model 3) resulted in a decrease in the PR of sensitivity to bitter taste.

There was no significant association between the detection threshold of bitter taste and poor appetite (P=0.214, Chi-square test).

Discussion

The results of the present study showed a significant association between underweight and high detection threshold for bitter taste in middle- to old-aged Sri Lankan people, even after adjusting for multiple confounding factors and taking into account facilities of the residents. These results agree with those from a cross-sectional study on 46 American men with chronic obstructive pulmonary disease showing that underweight subjects had a significantly higher recognition threshold for bitter taste than normal-weight subjects (11). These results support the hypothesis that low taste sensitivity, especially

to bitter taste, may be one factor associated with underweight in developing countries.

Although we hypothesized that low sensitivity of bitter taste may result in undernutrition, other studies showed contradictory results. Bitterness often predicts toxicity and can be the principal cause of food rejection (23). It follows that subjects with low sensitivity to bitter taste may be more receptive to any type of food, resulting in weight increase. In fact, an Italian study on 75 volunteers aged 20 to 29 showed that responsiveness to 6-*n*-propylthiouracil (PROP), a bitter thiourea compound, was inversely related to BMI (24). The association between PROP taster status and BMI has often been investigated, but with contradictory results (25,26). The present study did not use PROP, which distinguishes between nontasters, regular tasters and supertasters of PROP on the basis of thresholds. Further studies using PROP are needed to clarify the details of the association between sensitivity to bitter taste and underweight.

There is another possible explanation for the association between underweight and low sensitivity to bitter taste. Studies have implicated undernutrition *per se* as a causative factor in producing alterations in taste (27). For example, low nutrient supplies may affect turnover of taste receptor cells. Further longitudinal studies are needed to clarify this possibility.

Subjective taste ability was not associated with underweight in the present study. This result contradicted the part of our hypothesis that stated that low taste sensitivity causes subjective taste difficulty, resulting in undernutrition. In addition, subjective taste ability was not associated with taste sensitivity in any taste in the present study ($P>0.05$, Chi-square test; data not shown). Similarly, there was no significant association between the detection threshold of bitter taste and poor appetite. These suggest that taste sensitivity was directly associated with undernutrition, and that subjective taste ability and poor appetite did not mediate the association. Cross-sectional (6,7) and cohort (8) studies showed that poor subjective appetite was associated with undernutrition, but the contradictory results may be due to the fact that these studies (6-8) were conducted in developed countries, one study (6) used energy intake as an outcome, and one study used patients (7). As the prevalence of taste blindness is particularly high in Southeast Asia (28), some underweight subjects may have genetically poor sensitivity and did not have a poor subjective appetite. Further cohort studies examining taste blindness are needed to clarify this issue.

High number of medications used was negatively associated with underweight, and users of medicines for hypertension and diabetes had a lower percentage of underweight than nonusers in the

present study. A WHO study showed that a significant proportion of patients did not receive appropriate medication for coronary heart disease in low- and middle-income countries (29). This suggests that the socio-economic status of the subjects taking medicine may be relatively high and their nutritional status may be better than subjects not taking medication. Furthermore, participants using medicine may be more “healthy minded” than non-users. Similar results were obtained in a prospective population-based study showing that light medication use decreased the risk of undernutrition in women (8).

It is well known that many types of medications can induce taste disorders (30). It is therefore of interest to know the association between taste sensitivity and medication. Among subjects in the present study, (P=0.001, Chi-square test,) but not with the other kinds of taste (P>0.05) (data not shown). Both subjects with the highest sensitivity and lowest sensitivity to bitter taste tended to take a higher number of medications. Use of common medications, which were used by more than 10% of the subjects (e.g. medicine for hypertension, cardiovascular disease and diabetes and vitamins) was not associated with sensitivity of bitter taste (P>0.05, Chi-square test). The PR of sensitivity to bitter taste did not change very much after adding number and kinds of medications to multivariate model 1, suggesting that medication may not mediate the association between sensitivity to bitter taste and underweight.

Number of teeth present and Eichner classification were not associated with underweight in the present study. To further explore this issue, we analyzed the association between subjective chewing ability and underweight. Subjective chewing ability was ascertained by asking, “Do you have difficulty eating any food?” with possible answers of “yes” or “no”. There was no significant association between the two variables (P=0.928, Chi-square test, data not shown). Neither number of teeth present nor chewing ability were associated with underweight in the present study, possibly because chewing ability can be modified by cooking (e.g., cooking soft meals aids mastication) and the study subjects were nursing home residents. As the results from studies on the association between number of teeth present and chewing ability and underweight are inconclusive (31,32), further cohort studies and intervention studies are needed to clarify this issue.

Some strengths of the present study are the large sample size and control for many potential confounding factors. However, the present study also has a number of limitations. First, BMI was used as a measure to evaluate underweight in the present study. BMI is easy to calculate and administrate, but it is uncertain whether or not BMI is a sufficiently sensitive indicator for nutritional status in older

subjects (33). Percentage weight loss and other health related parameters of the individual as included in the Mini Nutritional Assessment (MNA) (34), associated medical problems, and current nutrition intake should also be incorporated in nutritional evaluation to confirm the results of the present study.

Second, because the present study is a cross-sectional design, it is unknown when subjects with high thresholds for bitter taste lost their taste sensitivity. As previously mentioned, the prevalence of PROP nontasters (taste blindness) is relatively high in Southeast Asia (28), so underweight subjects may have genetically poor sensitivity. On the other hand, studies suggest that age-related changes are not uniform across qualities of taste: thresholds for salty and bitter taste were significantly increased with age but those of sour and sweet taste were not (35). Age group was significantly associated with taste sensitivity of sweet (P=0.040 Chi-square test) and bitter (P=0.022) tastes, but not salty, sour and umami tastes in the present study (data not shown). A cohort study is needed to further clarify this factor.

Third, the distribution of sour taste sensitivity was skewed to high concentration because the range of concentration of the sour taste solution was relatively overestimated. Additional studies are needed to confirm the results of the present study using a taste solution with a wider range of concentrations.

Conclusions

The present cross-sectional study revealed a possibility that middle- to old-aged Sri Lankans with a high detection threshold for bitter taste may be at risk for underweight. A cohort study is needed to confirm this possibility.

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Table 1. Univariate associations of taste variables and covariates with underweight.

		Total	Underweight		PR	95% CI	*P*
		n	n	%			
Taste variables							
Detection threshold							
Sweet (% (w/w))	0.3	49	19	38.8	1.00		
	1	290	111	38.3	0.99	(0.61-1.60)	0.958
	3	401	171	42.6	1.10	(0.68-1.77)	0.695
	10	137	54	39.4	1.02	(0.60-1.71)	0.952
	>10.0	69	38	55.1	1.42	(0.82-2.46)	0.212
Salty (% (w/w))	0.1	61	21	34.4	1.00		
	0.3	522	206	39.5	1.15	(0.73-1.80)	0.550
	1	123	48	39.0	1.13	(0.68-1.89)	0.633
	3	158	84	53.2	1.54	(0.96-2.49)	0.075
	>3.0	82	34	41.5	1.20	(0.70-2.08)	0.503
Sour (% (w/w))	0.01	12	6	50.0	1.00		
	0.03	29	13	44.8	0.90	(0.34-2.36)	0.825
	0.1	89	28	31.5	0.63	(0.26-1.52)	0.304
	0.3	459	192	41.8	0.84	(0.37-1.88)	0.667
	>3.0	357	154	43.1	0.86	(0.38-1.95)	0.722
Bitter (% (w/w))	0.0001	90	25	27.8	1.00		
	0.0003	298	120	40.3	1.45	(0.94-2.23)	0.092
	0.001	308	132	42.9	1.54	(1.01-2.37)	0.047
	0.003	155	66	42.6	1.53	(0.97-2.43)	0.069
	>0.003	95	50	52.6	1.89	(1.17-3.06)	0.009
Umami (% (w/w))	0.1	774	323	41.7	1.00		
	>0.1	172	70	40.7	0.98	(0.75-1.26)	0.850
Subjective taste ability	No problem	768	308	40.1	1.00		
	Problem	178	85	47.8	1.19	(0.94-1.51)	0.151
Covariates							
Sex	Male	383	193	50.4	1.00		
	Female	563	200	35.5	0.70	(0.58-0.86)	0.001
Age (years)	50-59	80	23	28.8	1.00		
	60-69	278	103	37.1	1.29	(0.82-2.03)	0.272
	70-79	367	160	43.6	1.52	(0.98-2.35)	0.062
	80-89	196	96	49.0	1.70	(1.08-2.69)	0.022
	≥90	25	11	44.0	1.53	(0.75-3.14)	0.246
Ethnicity	Sinhala	881	366	41.5	1.00		
	Tamil	52	22	42.3	1.02	(0.66-1.56)	0.934
	Other	13	5	38.5	0.93	(0.38-2.24)	0.864
No. years at nursing home	<3.0	396	168	42.4	1.00		
	3.0-5.9	282	127	45.0	1.06	(0.84-1.34)	0.611
	6.0-8.9	122	40	32.8	0.77	(0.55-1.09)	0.143
	9.0-11.9	81	28	34.6	0.81	(0.55-1.22)	0.315
	≥12.0	65	30	46.2	1.09	(0.74-1.60)	0.671
Activities of daily living	0	336	124	36.9	1.00		
	1	310	139	44.8	1.22	(0.95-1.55)	0.116
	2	130	51	39.2	1.06	(0.77-1.47)	0.713
	3	104	43	41.3	1.12	(0.79-1.59)	0.520
	≥4	66	36	54.5	1.48	(1.02-2.14)	0.039
Exercise	Never	609	268	44.0	1.00		

	≥Once/day	337	125	37.1	0.84	(0.68-1.04)	0.113
Bowel movements	No problem	532	212	39.8	1.00		
	Problem	414	181	43.7	1.10	(0.90-1.34)	0.357
Smoking status	Never	643	230	35.8	1.00		
	Current/past	303	163	53.8	1.50	(1.23-1.84)	<0.001
Drinking status	Never	639	236	36.9	1.00		
	Current/past	307	157	51.1	1.38	(1.13-1.69)	0.002
Chronic diseases	0	241	103	42.7	1.00		
	1	405	179	44.2	1.03	(0.81-1.32)	0.784
	2	238	92	38.7	0.90	(0.68-1.20)	0.484
	≥3	62	19	30.6	0.72	(0.44-1.17)	0.183
Number of medications	0	290	141	48.6	1.00		
used	1	286	118	41.3	0.85	(0.66-1.08)	0.190
	2	212	83	39.2	0.80	(0.61-1.05)	0.116
	3	123	43	35.0	0.72	(0.51-1.01)	0.058
	≥4	35	8	22.9	0.47	(0.23-0.96)	0.038
Kinds of medication used							
Hypertension	No	594	272	45.8	1.00		
	Yes	352	121	34.4	0.73	(0.59-0.91)	0.006
Cardiovascular	No	778	336	43.2	1.00		
diseases	Yes	168	57	33.9	0.78	(0.58-1.03)	0.083
Vitamins	No	798	336	42.1	1.00		
	Yes	148	57	38.5	0.91	(0.68-1.22)	0.525
Diabetes	No	804	352	43.8	1.00		
	Yes	142	41	28.9	0.67	(0.49-0.93)	0.016
Asthma	No	867	359	41.4	1.00		
	Yes	79	34	43.0	1.03	(0.72-1.47)	0.886
Mental disorders	No	870	368	42.3	1.00		
	Yes	76	25	32.9	0.79	(0.52-1.19)	0.252
Self-reporting	0-1	153	65	42.5	1.00		
questionnaire	2-3	351	149	42.5	1.00	(0.75-1.34)	0.995
20 items	4-5	258	109	42.2	0.99	(0.73-1.35)	0.970
	6-7	105	39	37.1	0.87	(0.59-1.30)	0.509
	≥8	79	31	39.2	0.92	(0.60-1.42)	0.717
Subjective smell ability	No problem	788	318	40.4	1.00		
	Problem	158	75	47.5	1.18	(0.91-1.51)	0.206
Number of teeth present	≥20	133	49	36.8	1.00		
	10 - 19	171	55	32.2	0.87	(0.59-1.28)	0.488
	1 - 9	254	119	46.9	1.27	(0.91-1.77)	0.158
	0	388	170	43.8	1.19	(0.87-1.63)	0.286
Eichner classification	Group A	52	18	34.6	1.00		
	Group B	288	108	37.5	1.09	(0.66-1.81)	0.735
	Group C	606	267	44.1	1.28	(0.79-2.08)	0.314
Flow rate of saliva	<0.5	261	102	39.1	1.00		
	0.5 - 0.9	428	170	39.7	1.02	(0.80-1.30)	0.898
	1.0 - 1.4	223	100	44.8	1.15	(0.87-1.51)	0.328
	≥1.5	34	21	61.8	1.58	(0.99-2.53)	0.056

The dependent variable in the model takes the value of 1 if BMI is less than 18.5 and 0 if BMI is equal or more than 18.5.

Table 2. Association of underweight with individual level variables determined by using multilevel Poisson regression.

	Model 1			Model 2			Model 3		
	Multilevel PR	95% CI	*P*	Multilevel PR	95% CI	*P*	Multilevel PR	95% CI	*P*
Fixed effects									
Detection threshold									
Bitter (% (w/w))									
0.0001	1.00			1.00			1.00		
0.0003	1.47	(0.95 - 2.29)	0.086	1.48	(0.95 - 2.30)	0.084	1.46	(0.94 - 2.28)	0.093
0.001	1.47	(0.95 - 2.29)	0.083	1.48	(0.95 - 2.29)	0.084	1.46	(0.94 - 2.27)	0.095
0.003	1.38	(0.86 - 2.22)	0.183	1.43	(0.89 - 2.31)	0.142	1.38	(0.86 - 2.24)	0.186
>0.003	1.77	(1.08 - 2.90)	0.022	1.79	(1.09 - 2.93)	0.020	1.70	(1.04 - 2.80)	0.036
Sex									
Male	1.00			1.00			1.00		
Female	0.90	(0.62 - 1.30)	0.563	0.94	(0.65 - 1.37)	0.762	0.97	(0.67 - 1.39)	0.852
Age (years)									
50-59	1.00			1.00			1.00		
60-69	1.29	(0.82 - 2.04)	0.277	1.31	(0.82 - 2.07)	0.254	1.28	(0.81 - 2.04)	0.291
70-79	1.49	(0.94 - 2.36)	0.091	1.49	(0.94 - 2.37)	0.090	1.48	(0.93 - 2.34)	0.099
80-89	1.60	(0.97 - 2.63)	0.064	1.56	(0.95 - 2.57)	0.080	1.53	(0.93 - 2.53)	0.096
≥90	1.41	(0.65 - 3.03)	0.383	1.44	(0.67 - 3.12)	0.352	1.48	(0.68 - 3.19)	0.321
Activities of daily living									
0	1.00			1.00			1.00		
1	1.08	(0.82 - 1.41)	0.593	1.13	(0.86 - 1.48)	0.395	1.13	(0.86 - 1.49)	0.372
2	0.95	(0.65 - 1.38)	0.785	1.00	(0.69 - 1.47)	0.983	1.00	(0.69 - 1.46)	0.990
3	0.99	(0.67 - 1.48)	0.978	0.99	(0.66 - 1.48)	0.961	0.99	(0.66 - 1.48)	0.963
≥4	1.20	(0.80 - 1.81)	0.372	1.20	(0.79 - 1.80)	0.389	1.22	(0.81 - 1.84)	0.336
Smoking status									
Never	1.00			1.00			1.00		
Current/past	1.41	(0.93 - 2.14)	0.102	1.45	(0.96 - 2.19)	0.080	1.47	(0.97 - 2.24)	0.068
Alcohol status									
Never	1.00			1.00			1.00		

Current/past	0.97	(0.67 - 1.40)	0.855	0.96	(0.66 - 1.39)	0.841	0.97	(0.67 - 1.40)	0.859
Number of medications used									
0				1.00			1.00		
1				0.98	(0.75 - 1.27)	0.871	0.96	(0.74 - 1.26)	0.783
2				0.98	(0.70 - 1.38)	0.913	0.97	(0.69 - 1.36)	0.863
3				1.00	(0.63 - 1.57)	0.986	0.96	(0.61 - 1.52)	0.878
≥4				0.65	(0.29 - 1.42)	0.278	0.63	(0.28 - 1.38)	0.245
Kinds of medication used									
Hypertension									
No				1.00			1.00		
Yes				0.78	(0.58 - 1.04)	0.093	0.79	(0.59 - 1.06)	0.117
Diabetes									
No				1.00			1.00		
Yes				0.78	(0.54 - 1.12)	0.173	0.78	(0.54 - 1.12)	0.178
Flow rate of saliva (g/2 min)									
<0.5							1.00		
0.5 - 0.9							0.97	(0.75 - 1.25)	0.799
1.0 - 1.4							1.07	(0.81 - 1.42)	0.634
≥1.5							1.51	(0.93 - 2.45)	0.096
Intercept	0.18	(0.09 - 0.35)	<0.001	0.19	(0.10 - 0.38)	<0.001	0.19	(0.10 - 0.39)	<0.001
Random effects									
Community-level variance (SE)	0.034	0.028		0.039	0.030		0.041	0.031	

The dependent variable in the model takes the value of 1 if BMI is less than 18.5 and 0 if BMI is equal or more than 18.5.
Null model: Intercept, multilevel PR: 0.41(0.35-0.46), *P*<0.001, community-level variance (SE): 0.041 (0.030).