

Poor oral health and the association with diet quality and intake in older people in two studies in the UK and USA

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Abbreviations used: BRHS, British Regional Heart Study; HABC, Health, Aging and Body Composition; FFQ, Food Frequency Questionnaire; EDI, Elderly Dietary Index; HEI, Healthy Eating Index; CVD, cardiovascular disease; OR, odds ratio; CI, confidence interval.

Information on data sharing can be found a) for the British Regional Heart Study at: <https://www.ucl.ac.uk/epidemiology-health-care/research/primary-care-and-population-health/research/brhs/> and b) for the Health, Aging and Body Composition Study at: <https://healthabc.nia.nih.gov/>.

Abstract

We aimed to investigate associations of poor oral health cross-sectionally with diet quality and intake in older people. We also examined whether change in diet quality is associated with oral health problems. Data from the British Regional Heart Study (BRHS) comprising British males aged 71-92 years, and the Health, Aging and Body Composition (HABC) Study comprising American males and females aged 71-80 were used. Dental data included tooth loss, periodontal disease, dry mouth, and self-rated oral health. Dietary data included diet quality (based on Elderly Dietary Index (BRHS), and Healthy Eating Score (HABC Study)) and several nutrients. In the BRHS, change in diet quality over 10 years (1998-2000 to 2010-2012) was also assessed. In the BRHS, tooth loss, fair/poor self-rated oral health and accumulation of oral health problems were associated with poor diet quality, after adjustment. Similar associations were reported for high intake of processed meat. Poor oral health was associated with top quartile of percentage of calories from saturated fat (self-rated oral health, odds ratio (OR)=1.34, 95% CI 1.02-1.77). In the HABC study, no significant associations were observed for diet quality after adjustment. Periodontal disease was associated with top quartile of percentage of calories from saturated fat (OR=1.48, 95%CI 1.09-2.01). In the BRHS, persistent low diet quality was associated with higher risk of tooth loss and accumulation of oral health problems. Older individuals with oral health problems had poorer diets and consumed fewer nutrient-rich foods. Persistent poor diet quality was associated with oral health problems later in life.

Introduction

Oral health problems such as tooth loss, periodontal disease and dry mouth are very common conditions in older people (≥ 65 years), and have significant impacts on health ⁽¹⁾. Poor oral health in older age, has been associated with the development of chronic conditions, such as disability, cardiovascular disease, and increased risk of mortality ^(2; 3; 4). Moreover, older people are at risk of following a poor diet, particularly avoidance of specific foods or frequent consumption of unhealthy food, which can adversely influence their nutritional intake, quality of life and general well-being ⁽⁵⁾. Poor oral health can play an important part in changes in dietary habits and variety of food intake, but at the same time an unhealthy diet may also affect oral health ⁽⁵⁾, suggesting a bidirectional relationship between poor oral health and diet in older people.

Tooth loss, in particular, has been found to be associated with low intakes of fruits and vegetables, vitamin C, vitamin E, as well as higher consumption of processed foods and fatty acids in adults (>18 years) ^(6; 7; 8; 9; 10). It is possible that the association between oral health and fat intake may be due to higher consumption of processed meat which is a source of saturated fat which is easy to chew and requires little preparation ^(11; 12; 13). Tooth loss was also associated with poor diet quality and low protein intake in older people ^(7; 12; 14; 15). However, these findings were not consistent in all studies ^(16; 17). Furthermore, having a good oral function (optimal number of teeth and ability to chew) was found to be associated with higher consumption of protein and vegetables and decreased consumption of calories and fats in some studies ^(14; 18; 19), but similar to tooth loss, results were not consistently reported by other studies ^(17; 20). Moreover, periodontal disease was associated with low intake of percentage of calories from fat in adults ⁽²¹⁾, whereas dry mouth, particularly hyposalivation,

was associated with lower consumption of fruits and vegetables in older people ⁽²²⁾. Additionally, studies have found that poor diet quality, and increased intake of saturated fat were associated with the progression of periodontal disease (chronic gum disease) and tooth loss in older adults ^(23; 24). Furthermore, diets rich in antioxidants and low in saturated fats led to an improvement in the severity of periodontal disease in adults ⁽²⁵⁾.

These studies support the presence of a bidirectional association of poor oral health with diet quality and intake. However, there is no consensus on the specific nutrients associated with poor oral health in older people. Furthermore, the majority of previous studies have focused on tooth loss and periodontal disease. There is lack of evidence on the associations of other markers of oral health such as dry mouth and self-rated oral health with dietary intake in older people. Hence, we aimed to examine the associations of objectively and subjectively assessed oral health markers with diet quality and dietary intake, as well as changes in diet quality over 10 years, and their associations with poor oral health in samples of community-dwelling older people in the UK and USA.

Subjects and Methods

We used data from the British Regional Heart Study in the UK and the Health, Aging and Body Composition Study in the US. The study is reported according to the STROBE guidelines.

The British Regional Heart Study

This is an ongoing cohort study which at baseline comprised 7735 males aged 40-59 years. Individuals were recruited from 24 towns across the UK in 1978-80 and have been followed-up since ⁽²⁶⁾. For this study, data from the 20-year and 30-year follow-up were used. In 1998-

2000, 4252 males (77% response rate) aged 60-79 years participated in the 20-year follow-up physical examination and completed postal questionnaires. A 30-year follow-up of the cohort was undertaken in 2010-2012 and was attended by 2147 surviving participants aged 71-92 years. Participants completed a postal questionnaire (68% response rate), participated in the physical and oral health examination (n=1722) (55% response rate) and had blood samples taken⁽²⁶⁾. Examinations were conducted by a trained research nurse and took place in each of the 24 towns of the study in community-based venues. Information on missing data and attrition is presented in supplemental Figure 1. Ethical approval was provided by the National Research Ethics Service (NRES) Committee, London. Written informed consent was obtained from individuals for their participation in the study, according to the Declaration of Helsinki⁽²⁷⁾.

The Health, Aging, and Body Composition Study (HABC Study)

The HABC Study is a prospective population-based study investigating deterioration in physical function of older individuals and how changes in body composition influence health in older age. Baseline data collection took place in 1997-1998, where 3075 white and African-American males and females aged 70-79 years were recruited. Random selection of White participants was performed through Medicare, whereas African-American were selected through neighbourhoods with a ZIP code around Memphis and Pittsburgh⁽²⁸⁾. At baseline, individuals who were not able to walk 0.25 miles or climb 10 steps were excluded from the study. In Year 2 (1998-1999), data from males and females aged 71-80 years (n=3075) were used. Measurements included an oral health (n=1975) and physical assessment, collection of blood samples and completion of questionnaires. Oral examination was conducted at the research centre by a dental hygienist or a periodontist. Details on missing data and attrition are presented in supplemental Figure 2. All participants provided

written informed consent. Ethical approval was provided by University of Pittsburgh, University of Tennessee – Memphis, UCSF and NIH⁽²⁸⁾.

Oral health markers

In both studies, oral health was assessed through an oral examination and completion of questionnaires and included objectively and subjectively assessed oral health markers. Objective markers (oral examination) included count of natural teeth, and periodontal disease measures (loss of attachment and pocket depth)^(1; 29). Details of the examination of periodontal disease can be found elsewhere^(1; 29). Subjective (self-rated) oral health markers (questionnaires) comprised self-rated oral health, dry mouth, difficulty eating due to mouth, teeth or dentures problems, sensitivity to hot/cold/sweets, and limitation of food due to gum problems. In the HABC Study, one question was used to assess dry mouth (dry mouth when eating). In the BRHS, the Xerostomia Inventory Scale, which consists of 11 questions, was used to measure dry mouth and groups (number of symptoms) were created according to the responses provided⁽³⁰⁾.

Dietary intake and diet quality

In the BRHS, dietary intake was assessed at two time points at the 20-year (age 60-79 years) and 30-year (aged 71-92 years) follow-up by a postal Food Frequency Questionnaire (FFQ) which was developed for use in the WHO's Monitoring Trends and Determinants in Cardiovascular Disease Survey, and has been validated in the British population⁽³¹⁾. For the measurement of diet quality, the Elderly Dietary Index (EDI) was utilised, which is based on the US Modified MyPyramid for Older Adults and other recommendations for older people⁽³²⁾. The EDI score comprises 9 food components (meat, fish and seafood, legumes, fruit,

vegetables, cereals, bread, olive oil and dairy)^(32; 33). Consumption of each food group was used to create the EDI score to indicate diet quality. Further details on the FFQ and EDI score can be found elsewhere⁽³³⁾. Dietary intake included protein, carbohydrates, calories from total and saturated fat, cholesterol, fruits and vegetables, sugar, and a range of micronutrients (vitamins C, E, iron, vitamin A, b-carotene, vitamin K1). The total macronutrient and micronutrient intakes were calculated by a validated computer programme which is based on UK food composition tables^(33; 34). The frequency of foods consumed was multiplied by the standard portion sizes for each food and by the nutrient composition of the foods obtained from the UK food composition tables^(32; 34). Then, according to these intakes, total energy intake was also calculated. Additionally, in order to examine whether potential associations between oral health and fat intake are a result of high consumption of processed meat, we created a variable about the intake of processed meat. In the BRHS, consumption of bacon, salami, tinned meat, corned beef, pork and beef sausages, meat pie and pasties were used to create this variable. In the HABC Study, processed meat consisted of ham, bacon, sausage, bologna, fried chicken. This variable was based on the number and frequency of processed meat consumed.

In the HABC Study, a 108-item, interviewer-administered modified version of the Block FFQ (Block Dietary Data Systems) was used for the assessment of dietary intake in Year 2 (1998-1999)^(35; 36). More details on the FFQ can be found elsewhere⁽³⁶⁾. The Healthy Eating Index (HEI) was used to assess diet quality, and shows whether an individual adheres to the Dietary Guidelines for Americans of 1995 and the Food Pyramid of 1992⁽³⁶⁾. HEI score is a validated tool for the assessment of diet quality for the US population, and is defined according to different sex and age groups^(36; 37). Therefore, it can be used to assess dietary intake of different age groups, including older people. HEI consists of 10 components; 9 food components (grains, vegetables, fruit, milk, and meat, intakes of percentages of calories from

total and saturated fat, total cholesterol, and total sodium) and 1 component which assess diet variety. In the HABC study, dietary intake also included trans-fat intake, percentage of energy from sweets and soda, and a number of micronutrients (vitamins B1, B2, B5, B6, C, D, E, A, B12, copper, magnesium, manganese, iron, calcium, phosphorus, potassium, zinc, folic acid). Similar to the BRHS, we created a variable about the consumption of processed meat. In both studies, protein intake was measured as g/kg body weight/day.

Covariates

In both studies, measures of socioeconomic position, smoking, alcohol, and history of doctor-diagnosed cardiovascular disease (CVD) and diabetes were self-reported through questionnaires ^(26; 29). In the BRHS, occupational social class was used to assess socioeconomic position on the basis of longest-held occupation at baseline ⁽³⁸⁾. In the HABC Study, the highest level of education accomplished, was the indicator of socioeconomic position ⁽²⁹⁾. To create body mass index (BMI), body weight and height assessed at physical examinations were utilised ^(39; 40). For both studies, total energy intake, was derived from FFQ questionnaires, and regular use of prescribed medications causing dry mouth (xerostomia) were identified ⁽⁴¹⁾.

Statistical Analysis

Logistic and regression analyses were performed for the BRHS and HABC Study separately to assess the associations of oral health markers with diet quality and majority of nutrients. Ordinal regression was performed for the associations between (a) poor oral health and three categories of processed meat, and (b) change in EDI score over time and oral health problems (4 categories) later in life. We observed no violations of the assumptions for logistic and

ordinal regression analyses. Two variables for number of natural teeth were created: (a) 0, 1-7, 8-14, 15-20 and ≥ 21 teeth; and (b) < 21 teeth and ≥ 21 teeth⁽⁴²⁾. Loss of attachment and pocket depth were markers of periodontal disease and the following categories were generated: in the BRHS – pocket depth $> 20\%$ sites affected > 3.5 mm and loss of attachment $> 20\%$ sites affected > 5.5 mm; in the HABC Study – both markers $> 20\%$ sites affected ≥ 3 mm^(38; 43). Self-rated oral health was a binary variable grouped as excellent/good, and fair/poor in both studies. In the BRHS, dry mouth was divided into 0, 1-2 or ≥ 3 dry mouth symptoms. In the HABC Study, dry mouth was categorised as either having dry mouth when eating or not. Moreover, to examine the burden of poor oral health, we created a variable indicating an accumulation of oral problems – in the BRHS, four oral health problems were used: < 21 natural teeth, ≥ 3 dry mouth symptoms, any difficulty eating and sensitivity to hot/cold/sweets⁽⁴⁴⁾; in the HABC Study, the measure included: < 21 natural teeth, dry mouth when eating, any difficulty eating and limitation of food due to gum problems. The variable was then categorised as 0, 1, 2, and ≥ 3 problems. In the BRHS, EDI scores were divided into quartiles; with the bottom quartile (worst diet quality) as the outcome variable in logistic regression models. In the HABC Study, HEI scores were categorised as good (> 80), needs improvement (51-80) and low (< 51) diet quality⁽³⁷⁾; ‘low HEI score’ (poor diet quality) was the outcome whereas needs improvement and good HEI scores were grouped together (reference group) in logistic regression models. In both studies, macro- and micronutrients were divided into quartiles and either the bottom or top quartile were outcomes in logistic regression models in order to indicate worse dietary intake⁽⁴⁵⁾. Consumption of processed meat was categorised as: 1= rarely/monthly (little intake), 2= 1 type of processed meat ≥ 2 times per week (moderate intake), 3= ≥ 2 types of processed meat ≥ 2 times per week; the third category (≥ 2 types of processed meat ≥ 2 times per week - indicating high intake) was the outcome in ordinal regression. Protein intake was a binary variable; in the BRHS low protein

consumption was categorised as <0.75 g/kg/d and high as ≥ 0.75 g/kg/d ⁽⁴⁶⁾, and in the HABC Study low as <0.8 g/kg/d and high as ≥ 0.80 g/kg/d ⁽⁴⁷⁾. Recommended values of fruits and vegetables intake were used as cut-off values in logistic regression. In the BRHS individuals with intake smaller than 5 portions/day and in the HABC Study participants with intake smaller than 6 portions/day were classified as having low intake of fruits and vegetables ^(48; 49). In the BRHS, regression models were adjusted for age, social class, smoking, alcohol, history of CVD and diabetes, BMI, and caloric intake. In the HABC Study, age, sex, race, education, smoking, alcohol, history of CVD and diabetes, BMI and caloric intake were included as potential confounders in the models.

Additionally, in the BRHS, change in the EDI scores was examined over 10 years between age 60-79 years and 71-92 years. Change in EDI scores was calculated as a 4-level variable (1=persistent poor EDI score, 2=decrease in score, 3= improvement, 4=persistent good score). Ordinal and logistic regression analyses were performed to test the association of change in EDI score with oral health markers at age 71-92 years. All analyses were performed using SAS, version 9.4 software (SAS Institute, Inc., Cary, North Carolina).

In both studies, we compared the distribution of characteristics between those with and without missing data to examine potential differences between the two groups.

Results

Baseline characteristics and prevalence of oral health markers can be found in Table 1. The mean age of BRHS participants (n=2,147) was 78.8 years, 52% were in non-manual social class, 20% had no remaining natural teeth and 35% reported fair/poor self-rated oral health. Moreover, 62% had at least 1 dry mouth symptom, whereas 36% reported at least 2 oral health problems. In the HABC Study (n=2,998), mean age of study subjects was 74.7 years, 52% were female, 58% White, and 42% reported postsecondary education. Also, 11% of the

HABC Study sample had no remaining natural teeth, 31% fair/poor self-rated oral health, 4% had dry mouth when eating and 22% at least 2 oral health problems.

Oral health and diet quality

Objective oral health markers

Odds ratios (OR) and 95% confidence intervals (CI) for the associations between oral health markers and diet quality in the BRHS and HABC Study are presented in Table 2. In the BRHS, having 8-14 teeth, were associated with the bottom quartile (poor diet quality) of EDI score (OR=1.57, 95% CI: 1.05-2.34), after adjusting for confounders. In the HABC Study, complete and partial tooth loss, and periodontal disease (loss of attachment), were associated with poor diet quality in the age adjusted models (0 vs. ≥ 21 teeth, OR=1.78, 95% CI 1.03-3.08; periodontal disease, OR=2.21, 95% CI 1.33-3.70). The associations for tooth loss were attenuated and did not remain after adjustment. For periodontal disease, the association was also attenuated after adjusting for confounders (OR=1.69, 95% CI 0.98-2.94).

Subjective oral health markers

In the BRHS fair/poor self-rated oral health and at least 3 oral health problems were associated with the bottom quartile (poor diet quality) of EDI score (OR=1.51, 95% CI: 1.14-1.99; OR= 1.83, 95% CI: 1.11-3.01, respectively), after full adjustment.

In the HABC Study, fair/poor self-rated oral health, dry mouth, and accumulation of oral health problems were associated with low HEI score (poor diet quality) in age-adjusted models (OR=1.68, 95% CI 1.26-2.24 for self-rated oral health, OR=1.84, 95% CI 1.03-3.29 for dry mouth), but these associations did not remain after adjusting for confounders.

Oral health and dietary intake

Table 3 presents the associations of poor oral health with energy intake, percentage of energy from saturated fat, and fruits and vegetables intakes in the BRHS. Associations between oral health problems and protein, vitamin C, and α -tocopherol intakes are presented in Appendix A (Figure A1). Associations between oral health and processed meat are presented in Appendix B, Figure B1.

Objective oral health markers

In the fully adjusted model, partial tooth loss (15-20 teeth vs. ≥ 21) was associated with the top quartile of caloric intake (OR=1.54, 95%CI 1.11-2.16). We did not observe any associations between markers of poor oral health and low protein intake. Complete and partial tooth loss were associated with increased consumption of processed meat and low fruits and vegetables intake (processed meat, OR=2.03, 95%CI 1.40-2.95; OR=1.64, 95% CI 1.12-2.38, respectively) after adjustment for confounders. The associations between oral health and processed meat did not remain after further adjustment for caloric intake. A borderline association was observed for periodontal disease and low fruits and vegetables intake in the age adjusted model (OR=1.52, 95% CI 1.00-2.30). This association did not change significantly after full adjustment (OR=1.52, 95% CI 0.96-2.40). Complete and partial tooth loss, and loss of attachment were associated with the bottom quartile of α -tocopherol in the fully adjusted models (see Appendix A, Figure A1). We did not observe any other associations between oral health markers and vitamins and minerals.

Subjective oral health problems

In the BRHS, ≥ 3 dry mouth symptoms and ≥ 3 oral health problems were associated with the top quartile of caloric intake (OR=1.58, 95%CI 1.17-2.13; OR=2.32, 95%CI 1.46-3.67, respectively) in the fully adjusted models. Moreover, fair/poor self-rated oral health and

having at least 3 oral health problems were associated with top quartile of percentage of calories from saturated fat, and low intake of fruits and vegetables. Having ≥ 3 oral health problems was associated with increased consumption of processed meat (OR=2.16, 95%CI 1.22-3.18) after adjustment for confounders. This association did not remain after adjusting for caloric intake. Furthermore, fair/poor self-rated oral health was associated with the bottom quartile of vitamin C in the fully adjusted model (OR=1.38, 95% CI 1.04-1.84) (see Appendix A, Figure A1). Finally, having ≥ 3 oral health problems was associated with the bottom quartile of a-tocopherol in the fully adjusted models (see Appendix A, Figure A1). We did not observe other associations between oral health markers and vitamins and minerals.

Associations of markers of poor oral health with dietary intake in the HABC Study can be found in Table 4 and Appendix C (Figure C1). Associations for oral health markers with processed meat are presented in Appendix B, Figure B1.

Objective oral health markers

Periodontal disease (pocket depth) was associated with the top quartile of caloric intake (OR=1.75, 95%CI 1.29-2.37) in the fully adjusted models (Table 4). Periodontal disease (loss of attachment) was the only oral health marker associated with the top quartile of percentage of calories from saturated fat after adjustment (Table 4), whereas complete and partial tooth loss were associated with the top quartile of calories from trans-fat (see Appendix C, Figure C1). Moreover, complete tooth loss (0 vs. ≥ 21 teeth) was associated with low intake of fruits and vegetables in the fully adjusted model (OR= 1.55, 95%CI 1.03-2.34) (Table 4). No significant associations were reported between poor oral health and low protein intake (see Appendix C, Figure C1). Additionally, periodontal disease (pocket depth) was associated with increased intake of processed meat after adjustment for age, sex, race, education,

smoking, alcohol, history of CVD and diabetes, and BMI. After adjusting further for caloric intake, this association did not remain significant (see Appendix B, Figure B1). We did not observe other associations between oral health markers and vitamins and minerals.

Subjective oral health markers

Having ≥ 3 oral health problems were associated with the top quartile of caloric intake (OR=1.49, 95%CI 1.04-2.15) in the fully adjusted model. For micronutrients, only having ≥ 3 oral health problems was associated with the bottom quartile of vitamin D intake (OR=1.77, 95% CI 1.21-2.58, fully adjusted) (see Appendix A, Figure A1). We did not observe other associations between oral health markers and vitamins and minerals.

Change in EDI score and prevalence of oral health problems (10 year follow up)

The associations for change in EDI score over a 10-year follow-up (age 60-79 to 71-92 years), with poor oral health at 71-92 years are presented in Table 5. In the age adjusted model, persistent low EDI score (low score at both time points) was associated with partial tooth loss (< 21 teeth vs. ≥ 21), periodontal disease, fair/poor self-rated oral health, and accumulation of oral health problems. After adjusting for confounders, associations for persistent low EDI score with tooth loss and having 2 oral health problems remained significant (OR=1.66, 95%CI 1.09-2.52; OR=1.96, 95%CI 1.07-3.56, respectively).

Missing data

In the BRHS, those with missing data were slightly older (1 year), were more likely to be in manual social class, consumed less alcohol, were less physically active and were more likely to report fair/poor general health. In the HABC study, participants with missing data were more likely to be African-American, current and former smokers, spent fewer years in school, consumed less alcohol, and were more likely to report poor general health.

Discussion

In this study, oral health problems in older age were associated with poor diet quality, higher intake of total energy, percentage of calories from saturated and trans-fat, low intake of fruits and vegetables, and high intake of processed meat. Additionally, in the BRHS, persistent low diet quality in older ages over a 10-year follow-up, were associated with having oral health problems later in life.

In the BRHS, tooth loss, fair/poor self-rated oral health and ≥ 3 oral health problems were associated with poor diet quality (lowest EDI scores). Similar associations for tooth loss have been supported by previous studies ^(7; 14). Individuals experiencing tooth loss were more likely to reduce consumption of specific vegetables (such as apples, carrots) as well as foods high in fibre, which influence diet quality ^(10; 50; 51). To our knowledge this is one of the first studies to report an association between fair/poor self-rated oral health and diet quality. This highlights the importance of the individual's perception of the oral health status and that it is possible that older people with fair/poor self-rated oral health have unhealthier diets. Our results also indicate that a greater burden of oral health problems (an accumulation of oral health problems) is associated with poorer diet quality. No independent significant associations for oral health markers with diet quality were reported in the HABC Study. However, the small number of individuals in the low HEI score group could have influenced the significance of the results observed.

In the BRHS, dry mouth was associated with increased caloric intake. Additionally, fair/poor self-rated oral health was associated with high intake of percentage of calories from saturated fat and low intake of fruits and vegetables. These findings again indicate that self-reported measures of oral health could be indicators of a compromised diet. In the HABC Study, periodontal disease was associated with top quartiles of both total caloric intake and

percentage of calories from saturated fat, in accordance with some previous studies ^(52; 53). One study reported that increased intake of saturated fat was associated with progression of periodontal disease in older people ⁽²⁴⁾. Furthermore, tooth loss was associated with low intake of fruits and vegetables and top quartiles of percentage of calories from trans-fat and calories from sweets and soda. Additionally, in both studies, poor oral health was associated with high intake of processed meat. The associations for low intake of fruits and vegetables are in accordance with previous studies ^(7; 8). In both our study populations, overall, we observed an increased consumption of meat and fish, cakes/cookies/desserts as well as high intake of liquid and solid fats. Additionally, mean intakes of percentage of energy from saturated and trans-fat were above the current recommendations ⁽⁴⁷⁾. However, associations for poor oral health with processed meat did not remain significant after adjusting for energy intake, suggesting that older people with oral health problems may follow diets high in calories and therefore are more likely to consume more processed meat too. We observed no associations between oral health markers and protein intake, which may be the result of overall levels of protein intake in both populations being within the recommended values ⁽⁴⁷⁾.

Persistent poor diet quality over 10 years of follow up in the BRHS was associated with partial tooth loss and accumulation of oral health problems; an association that was independent of confounders. These findings point to a potential bidirectional relationship between poor oral health and diet in older age. A previous study reported that following a diet rich in antioxidants, and vitamins and low in saturated and trans-fatty acids is linked to fewer teeth being lost ⁽⁵⁴⁾. Presence of oral health problems may lead to a compromised diet and poor diet quality due to food avoidance and change of dietary habits, whereas an unhealthy diet may also contribute to the deterioration of oral health in older people ⁽⁵⁵⁾.

A strength of our study is that we examined a wide range of macro- and micronutrients in two comparable studies of community-dwelling older people in two Western populations, and

were able to investigate bidirectional associations between poor oral health and diet quality in the BRHS. Moreover, this is one of the few studies examining the role of subjective oral health measures, such as dry mouth and self-rated oral health.

Our study has also limitations. Measurement of some oral health measures (i.e. periodontal disease, dry mouth) was different in the two studies, and some dietary intake variables (i.e. calories from trans-fat, micronutrients) were not available in both studies. Furthermore, different measures assessed diet quality in the two studies (EDI in BRHS; HEI in HABC Study), and therefore this may account for differences in the diet quality results between the two studies. It is also possible that our findings may not be representative of the general populations of the UK and USA because the BRHS consisted of White males, whereas the HABC Study comprised a subpopulation of older people in the US (White and African-American males and females from Pittsburgh and Memphis). The majority of our findings were cross-sectional, and therefore cannot establish causal relationships. When dietary intake is assessed by self-reported measures, including the FFQ method, it can lead to misreporting of intakes and this can introduce bias in the form of measurement error^(56; 57). This could influence the estimation of energy and micronutrient intakes^(56; 57). Nevertheless, the FFQs used in this study have been validated in the British and US populations^(31; 36; 58). We did not exclude participants with unintentional weight loss or extreme energy intake. However, in both studies, very small number of participants reported unintentional weight loss due to cancer or heart failure (BRHS n=59, 2.7%; HABC Study n=13, 0.4%, for cancer), or excessive energy intake (BRHS n=2, 0.1%; HABC Study n=77, 2.6%). Therefore, the results are unlikely to be biased due to unintentional weight loss or extreme energy intake. Furthermore, the presence of survivor bias is possible, since healthier participants are more likely to have attended the examinations. We also adjusted for a range of confounders, but residual confounding may be present, resulting in overestimation of the observed

associations. In both studies, multiple comparisons were performed, therefore increasing the risk of false-positive results. As the number of hypothesis testing increases, so does the risk of observing false-positive results ⁽⁵⁹⁾.

In conclusion, we observed that oral health problems were associated with poor diet quality and intake of micro- and macronutrients in two studies of community-dwelling older people in the UK and USA. Also, persistent poor diet quality was found to be associated with poor oral health later in life in the BRHS. These findings support a bidirectional association between poor oral health and diet. Future studies should further investigate the association between changes in diet and changes in oral health in older people. Additionally, future research should also focus on older people living in care homes to provide more evidence on how oral health influences diet and food choices. Further evidence can help design effective dietary programmes tailored to the oral health of older people, which could reduce the burden of poor oral health and its consequences in older people.

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Authorship

Study concept and design: EK, SER, SGW, AOP, PHW.

Acquisition of data: SER, SGW, AOP, PHW, LTL, RJW.

Analysis and interpretation of data: All authors.

Drafting of the manuscript: All authors.

Critical revision of the manuscript for important intellectual content: All authors.

Figures-Legends

Appendix A

Figure A1. Odds ratios and 95% confidence intervals for the association between poor oral health and dietary intake in older people in the BRHS.

Appendix B

Figure B1. Odds ratios and 95% confidence intervals for the association between oral health and processed meat intake in older people in the BRHS and HABC Study.

Appendix C

Figure C1. Odds ratios and 95% confidence intervals for the association between oral health and dietary intake in older people in the HABC Study.

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Table 1. Population characteristics and prevalence of oral health problems in the British Regional Heart Study (BRHS) and the HABC Study

BRHS (n=2,147)		HABC Study (n=2998)	
Age (years), mean ± standard deviation	78.8 ± 4.8	Age (years), mean ± standard deviation	74.7 ± 2.9
Social class, n (%)		Sex, n (%)	
Nonmanual	1081 (52%)	Male	1491 (48%)
Manual	1003 (48%)	Female	1584 (52%)
Smoking, n (%)		Race, n (%)	
Never	768 (36%)	White	1794 (58%)
Long-term exsmoker (gave up before 1983)	1153 (54%)	African-American	1281 (42%)
Recent exsmoker	122 (6%)	Education, n (%)	
Current smoker	91 (4%)	Less than high school	775 (26%)
Alcohol consumption, n (%)		High school graduate	1000 (33%)
Daily/most days	757 (36%)	Postsecondary	1292 (42%)
No consumption	292 (14%)	Smoking*, n (%)	
History of cardiovascular disease, n (%)	500 (24%)	Never	1348 (44%)
History of diabetes, n (%)	321 (16%)	Current smoker	318 (10%)
Body Mass Index, n (%)		Former	1404 (46%)
Normal	486 (29%)	Alcohol consumption*, n (%)	
Overweight	875 (51%)	More than 1 per day	227 (7%)
Obese	343 (20%)	No consumption in the past year	1546 (50%)
		History of cardiovascular disease, n (%)	106 (4%)
		History of diabetes, n (%)	142 (5%)
		Body Mass Index, n (%)	
		Normal	963 (34%)
		Overweight	1192 (42%)
		Obese	673 (24%)
Oral health measures		Oral health measures	
Edentulism (no natural teeth)	338 (20%)	Edentulism (no natural teeth)	207 (11%)
<21 teeth	1066 (64%)	<21 teeth	1031 (52%)
>20 % sites with loss of attachment >3.5mm	303 (24%)	>20 % sites with loss of attachment ≥3mm	721 (64%)
>20% sites with pocket depth >5.5mm	365 (29%)	>20% sites with pocket depth ≥3mm	627 (55%)
Fair/poor self-rated oral health	719 (35%)	Poor self-rated oral health	829 (31%)
≥ 1 dry mouth symptoms	1272 (62%)	Dry mouth when eating	107 (4%)
≥ 2 oral health problems	766 (36%)	≥ 2 oral health problems	617 (22%)

*Baseline data (Year 1)

Table 2. Odds ratios and 95% CI for the association of oral health markers with Elderly Dietary Index (EDI) and Healthy Eating Index (HEI) scores in older British men aged 71-92 years in the BRHS and older American men and women aged 71-80 years in the HABC Study.

	BRHS		HABC Study	
	Poor diet quality (Bottom quartile of EDI score)(11-22) (n=470; 25%)		Poor diet quality (low HEI group) (<51) (n= 216; 8%)	
	Age-adjusted OR (95% CI)	Fully-adjusted OR* (95% CI)	Age-adjusted OR (95% CI)	Fully-adjusted OR* (95% CI)
Tooth Loss			Tooth Loss	
≥21 teeth	1.00	1.00	≥21 teeth	1.00
15-20 teeth	1.47 (1.03, 2.08)	1.30 (0.89, 1.90)	15-20 teeth	1.74 (1.11, 2.74)
8-14 teeth	1.84 (1.28, 2.65)	1.57 (1.05, 2.34)	8-14 teeth	1.57 (0.95, 2.60)
1-7 teeth	1.74 (1.07, 2.85)	1.54 (0.90, 2.62)	1-7 teeth	2.17 (1.27, 3.70)
0 teeth	1.76 (1.24, 2.49)	1.34 (0.90, 2.01)	0 teeth	1.78 (1.03, 3.08)
Periodontal disease (% of sites with loss of attachment >5.5 mm)			Periodontal disease (% of sites with loss of attachment ≥3 mm)	
≤20%	1.00	1.00	≤20%	1.00
>20%	1.33 (0.96, 1.84)	1.28 (0.89, 1.82)	>20%	2.21 (1.33, 3.70)
Self-rated oral health			Self-rated oral health	
Good/Excellent	1.00	1.00	Good/Excellent	1.00
Fair/Poor	1.56 (1.25, 1.94)	1.51 (1.14, 1.99)	Fair/Poor	1.68 (1.26, 2.24)
Dry mouth symptoms			Dry mouth	
No dry mouth symptoms	1.00	1.00	No	1.00
1-2 dry mouth symptom	0.93 (0.71, 1.20)	0.85 (0.61, 1.17)	Yes	1.84 (1.03, 3.29)
≥3 dry mouth symptoms	1.02 (0.79, 1.33)	1.09 (0.79, 1.52)		
Cumulative oral health problems[†]			Cumulative oral health problems[†]	
0 oral health problems	1.00	1.00	0 oral health problems	1.00
1 oral health problem	1.64 (1.17, 2.28)	1.12 (0.78, 1.62)	1 oral health problem	1.70 (1.19, 2.45)
2 oral health problems	1.55 (1.08, 2.22)	0.97 (0.64, 1.48)	2 oral health problems	1.64 (1.03, 2.63)
≥3 oral health problems	2.06 (1.35, 3.15)	1.83 (1.11, 3.01)	≥3 oral health problems	1.49 (0.84, 2.65)

*BRHS: age, social class, smoking, alcohol, history of CVD and diabetes, BMI, caloric intake; HABC Study: age, sex, race, education, , smoking, alcohol, history of CVD and diabetes, BMI,

†BRHS: Includes <21 teeth, difficulty eating, symptoms of dry mouth, and sensitivity to hot, cold or sweet; HABC Study: dry mouth when eating, <21 remaining teeth, any difficulty eating or chewing, limit of food due to gum problems

Table 3. Odds ratios and 95% CI for the association of oral health markers with bottom quartile of caloric intake, top quartile of percentage of energy from saturated fat and low intake of fruits and vegetables in older British men aged 71-92 years in the BRHS.

	Top quartile of caloric intake (2,274-4,965 kcal/day) (n=490; 25%)		Top quartile of % of calories from saturated fat (n=446; 25%) (14.1-32.5%)		Mean fruits and vegetables intake (<5 portions/day) (n=231; n= 11%)	
	Age adjusted OR (95% CI)	Fully adjusted OR* (95% CI)	Age adjusted OR (95% CI)	Fully adjusted OR* (95% CI)	Age adjusted OR (95% CI)	Fully adjusted OR* (95% CI)
Tooth Loss						
≥21 teeth	1.00	1.00	1.00	1.00	1.00	1.00
15-20 teeth	1.41 (0.99, 2.02)	1.54 (1.11, 2.16)	1.03 (0.72, 1.46)	0.95 (0.65, 1.37)	1.62 (1.04, 2.54)	1.70 (1.04, 2.78)
8-14 teeth	1.49 (1.01, 2.19)	1.43 (0.99, 2.07)	1.37 (0.95, 1.98)	1.32 (0.89, 1.96)	1.55 (0.95, 2.53)	1.47 (0.86, 2.56)
1-7 teeth	1.44 (0.83, 2.48)	1.26 (0.75, 2.10)	1.62 (1.00, 2.64)	1.41 (0.83, 2.40)	1.19 (0.59, 2.38)	1.06 (0.48, 2.31)
0 teeth	1.31 (0.89, 1.92)	1.12 (0.77, 1.63)	0.89 (0.62, 1.29)	0.71 (0.47, 1.08)	2.01 (1.29, 3.11)	1.94 (1.04, 2.78)
Periodontal disease (% of sites with loss of attachment >5.5 mm)						
≤20%	1.00	1.00	1.00	1.00	1.00	1.00
>20%	1.34 (0.96, 1.87)	1.19 (0.86, 1.63)	1.32 (0.96, 1.81)	1.27 (0.90, 1.79)	1.52 (1.00, 2.30)	1.52 (0.96, 2.40)
Self-rated oral health						
Good/Excellent	1.00	1.00	1.00	1.00	1.00	1.00
Fair/Poor	1.10 (0.83, 1.44)	1.10 (0.85, 1.42)	1.38 (1.10, 1.74)	1.34 (1.02, 1.77)	1.55 (1.16, 2.06)	1.66 (1.16, 2.37)
Dry mouth symptoms						
No dry mouth symptoms	1.00	1.00	1.00	1.00	1.00	1.00
1-2 dry mouth symptom	1.34 (0.98, 1.83)	1.27 (0.95, 1.70)	0.97 (0.74, 1.26)	0.95 (0.69, 1.31)	0.88 (0.63, 1.23)	0.82 (0.54, 1.24)
≥3 dry mouth symptoms	1.49 (1.08, 2.06)	1.58 (1.17, 2.13)	1.20 (0.92, 1.56)	1.29 (0.93, 1.78)	0.95 (0.68, 1.34)	1.05 (0.69, 1.60)
Cumulative oral health problems[†]						
0 oral health problems	1.00	1.00	1.00	1.00	1.00	1.00
1 oral health problem	1.49 (1.04, 2.14)	1.26 (0.90, 1.77)	1.32 (0.94, 1.83)	1.18 (0.81, 1.70)	1.32 (0.87, 2.02)	1.08 (0.67, 1.75)
2 oral health problems	1.33 (0.88, 2.01)	1.28 (0.87, 1.88)	1.50 (1.05, 2.15)	1.31 (0.87, 1.98)	1.13 (0.70, 1.81)	1.03 (0.59, 1.78)
≥3 oral health problems	2.15 (1.32, 3.49)	2.32 (1.46, 3.67)	1.90 (1.24, 2.91)	1.68 (1.01, 2.78)	1.58 (0.92, 2.72)	1.60 (0.84, 3.07)

smoking, alcohol, history of CVD and diabetes, and BMI; for fruits and vegetables model caloric intake was added in the model

†<21 remaining teeth, ≥3 dry mouth symptoms, difficulty eating, sensitivity to hot/cold/sweets

* age, social class,

Table 4. Odds ratios and 95% CI for the association of oral health markers with bottom quartile of caloric intake, top quartile of percentage of calories from saturated fat and low intake of fruits and vegetables in older American men and women aged 71–80 years in the HABC Study.

	Top quartile of caloric intake (2,270-8,456 kcal/day) (n=678; 25%)		Top quartile of % of calories from saturated fat (11-23%) (n=678; 25%)		Mean fruits and vegetables intake (<6 portions/day) (n= 1789; 58%)	
	Age adjusted OR (95% CI)	Fully adjusted OR* (95% CI)	Age adjusted OR (95% CI)	Fully adjusted OR* (95% CI)	Age adjusted OR (95% CI)	Fully adjusted OR* (95% CI)
Tooth Loss						
≥21 teeth	1.00	1.00	1.00	1.00	1.00	1.00
15-20 teeth	1.30 (0.97, 1.73)	1.14 (0.84, 1.54)	1.38 (1.04, 1.84)	1.26 (0.93, 1.70)	1.02 (0.79, 1.31)	0.94 (0.71, 1.24)
8-14 teeth	1.42 (1.05, 1.93)	1.20 (0.86, 1.67)	1.32 (0.96, 1.81)	1.18 (0.85, 1.65)	1.31 (0.99, 1.74)	1.22 (0.89, 1.68)
1-7 teeth	1.70 (1.19, 2.41)	1.34 (0.92, 1.97)	1.51 (1.05, 2.17)	1.32 (0.90, 1.94)	0.95 (0.69, 1.31)	0.87 (0.59, 1.27)
0 teeth	1.53 (1.08, 2.16)	1.16 (0.79, 1.70)	1.36 (0.96, 1.95)	1.08 (0.73, 1.60)	1.60 (1.15, 2.22)	1.56 (1.03, 2.34)
Periodontal disease						
% of sites with loss of attachment ≥3 mm						
≤20%	1.00	1.00	1.00	1.00	1.00	1.00
>20%	1.20 (0.90, 1.60)	1.00 (0.74, 1.36)	1.48 (1.09, 2.01)	1.48 (1.09, 2.01)	1.11 (0.86, 1.43)	0.94 (0.70, 1.25)
% of sites with pocket depth ≥3 mm						
≤20%	1.00	1.00	1.00	1.00	1.00	1.00
>20%	2.05 (1.54, 2.72)	1.75 (1.29, 2.37)	1.43 (1.08, 1.88)	1.26 (0.94, 1.69)	1.09 (0.85, 1.39)	1.13 (0.85, 1.49)
Self-rated oral health						
Good/Excellent	1.00	1.00	1.00	1.00	1.00	1.00
Fair/Poor	1.22 (1.01, 1.46)	1.00 (0.81, 1.22)	0.82 (0.67, 1.01)	0.82 (0.67, 1.01)	1.19 (1.00, 1.42)	1.14 (0.94, 1.39)
Dry mouth						
No	1.00	1.00	1.00	1.00	1.00	1.00
Yes	1.13 (0.73, 1.75)	1.15 (0.73, 1.82)	1.05 (0.67, 1.66)	1.05 (0.67, 1.66)	0.95 (0.64, 1.42)	1.06 (0.68, 1.67)
Cumulative oral health problems[†]						
0 oral health problems	1.00	1.00	1.00	1.00	1.00	1.00
1 oral health problem	1.51 (1.22, 1.88)	1.33 (1.06, 1.67)	1.20 (0.96, 1.50)	1.20 (0.96, 1.50)	1.09 (0.91, 1.31)	1.02 (0.83, 1.25)
2 oral health problems	1.48 (1.11, 1.97)	1.24 (0.92, 1.69)	0.94 (0.69, 1.28)	0.94 (0.69, 1.28)	1.31 (1.01, 1.70)	1.22 (0.91, 1.62)
≥3 oral health problems	1.83 (1.30, 2.56)	1.49 (1.04, 2.15)	1.06 (0.73, 1.52)	1.06 (0.73, 1.52)	1.28 (0.93, 1.76)	1.11 (0.77, 1.60)

* adjusted for age, sex, race, education, smoking, alcohol, history of CVD and diabetes, BMI; for fruits and vegetables, caloric intake was added to the model

[†]<21 remaining teeth dry mouth when eating, any difficulty eating or chewing, limit of food due to gum problems

Table 5. Change in dietary quality (EDI scores) over 10 years (age 60-79 to 71-92 years) and the association with having oral health problems at 71-92 years in the BRHS.

EDI change over 10 years (60-79 yrs to 71-92 yrs)	Tooth loss (< 21 teeth) (n=933; 64%)		Loss of attachment (>20% sites affected) (n=265; 24%)		Self-rated oral health (fair/poor) (n=609; n=34%)			
	Age adjusted OR (95% CI)	Fully adjusted OR* (95% CI)	Age adjusted OR (95% CI)	Fully adjusted OR* (95% CI)	Age adjusted OR (95% CI)	Fully adjusted OR* (95% CI)		
Good score at both time points	1.00	1.00	1.00	1.00	1.00	1.00		
Score improved over 10 years	1.70 (1.20, 2.40)	1.41 (0.97, 2.06)	1.69 (1.06, 2.69)	1.46 (0.90, 2.37)	1.16 (0.83, 1.63)	1.17 (0.82, 1.66)		
Score decreased over 10 years	1.91 (1.32, 2.75)	1.61 (1.08, 2.38)	1.60 (0.98, 2.62)	1.33 (0.80, 2.21)	1.17 (0.84, 1.64)	1.08 (0.76, 1.54)		
Low score at both time points	2.35 (1.61, 3.42)	1.66 (1.09, 2.52)	1.77 (1.08, 2.88)	1.34 (0.78, 2.29)	1.44 (1.03, 2.01)	1.31 (0.91, 1.88)		
Cumulative oral health problems[†]								
EDI change over 10 years (60-79 yrs to 71-92 yrs)	0	Age adjusted OR (95% CI)			0	1	Fully adjusted OR* (95% CI)	
		1 (n=883; 46%)	2 (n=471; 25%)	≥3 (n=188; 10%)			2	≥3
Good score at both time points	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Score improved over 10 years	1.00	1.35 (0.89, 2.03)	1.51 (0.96, 2.39)	1.79 (0.97, 3.32)	1.00	1.13 (0.73, 1.76)	1.22 (0.74, 2.01)	1.35 (0.70, 2.61)
Score decreased over 10 years	1.00	1.94 (1.25, 3.02)	2.24 (1.38, 3.63)	2.50 (1.33, 4.69)	1.00	1.66 (1.04, 2.63)	1.81 (1.08, 3.03)	1.82 (0.93, 3.56)
Low score at both time points	1.00	3.62 (2.21, 5.94)	2.95 (1.71, 5.09)	3.17 (1.59, 6.34)	1.00	2.60 (1.52, 4.45)	1.96 (1.07, 3.56)	2.04 (0.96, 4.33)

* age, social class, smoking, alcohol, history of CVD and diabetes, BMI, caloric intake

† <21 remaining teeth, ≥3 dry mouth symptoms, difficulty eating, sensitivity to hot/cold/sweets

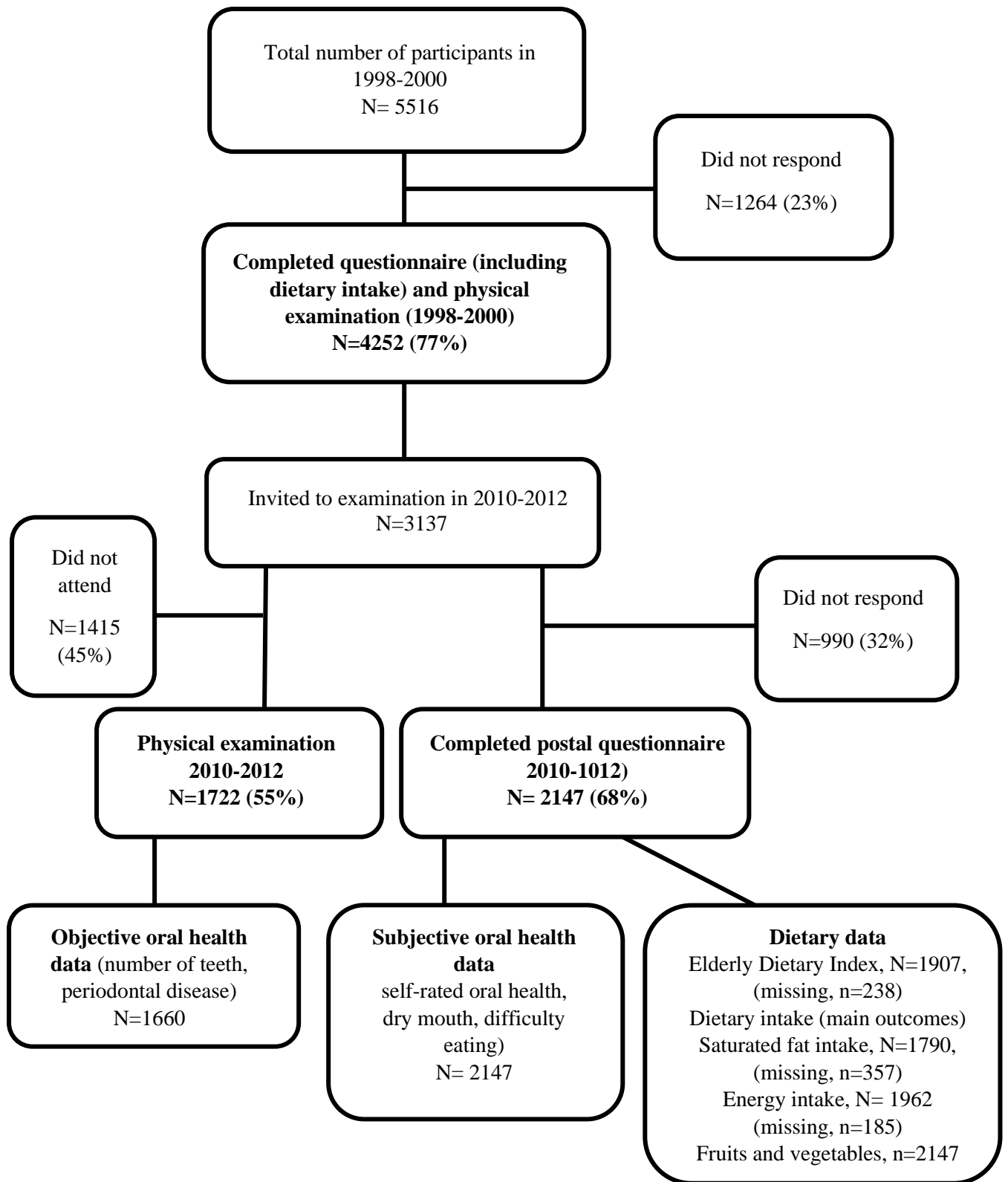


Figure 1. Flowchart of British Regional Heart Study participants followed up from 1998-2000 until 2010-2012.

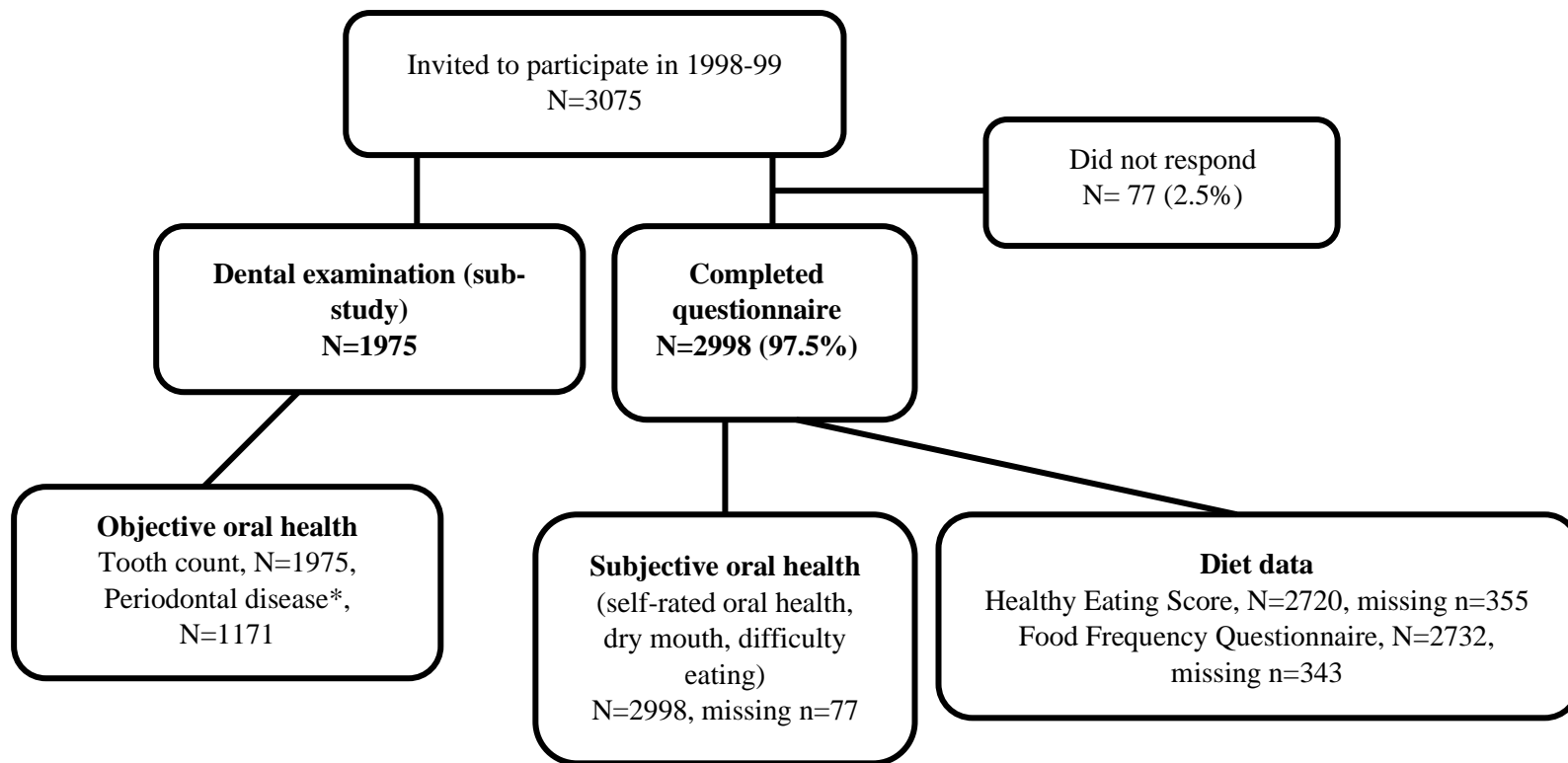


Figure 2. Flowchart of the Health, Aging and Body Composition Study participants aged 71-80 years at Year 2.

*eligible for a periodontal disease assessment