Association between oral health markers and decline in muscle strength and physical performance in later life: longitudinal analyses of two prospective cohorts from the UK and the USA

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Summary

Background Poor oral health could be associated with changes in musculoskeletal health over time. This aim of this study was to investigate the longitudinal relationship between oral health and decline in physical function in later life.

Methods We did a prospective analysis of two cohorts of older adults (aged 70 years or older) including men from the British Regional Heart Study (BRHS; n=612), and men and women from the Health, Aging and Body Composition (Health ABC) Study (n=1572), followed up for about 8 years. Data were available for clinical or self-reported oral health measures, muscle (grip) strength, and physical performance (chair stand and gait speed). ANCOVA models were used to assess the association between oral health and follow-up physical function scores. Multivariate logistic regression models were used to examine the associations between oral health and decline in physical function over the follow-up period. In the BRHS, changes in oral health and physical function were also assessed. All models were adjusted for relevant sociodemographic, behavioural, and health-related factors.

Findings In the BRHS, complete tooth loss and difficulty eating were associated with weaker grip strength at follow-up, and periodontal status was associated with decline in gait speed. In the Health ABC Study, complete tooth loss, poor self-rated oral health, and the presence of one oral health problem were associated with slower gait speed at follow-up. In both studies, dry mouth was associated with declines in physical function. In the BRHS, deterioration of dentition (tooth loss) over the follow-up period was associated with decline in chair stand speed (adjusted odds ratio 2·34 [95% CI 1·20–4·46]), as was deterioration in difficulty eating (2·41 [1·04–5·60]).

Interpretation Oral health problems are associated with poorer physical function and greater decline in physical function in older adults, and could be an indicator of individuals at risk of reduced physical capacity and subsequent frailty and disability in later life.

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Introduction

Poor physical capability is an important feature of unhealthy ageing that negatively affects quality of life and increases risk of mortality.[1–3] Declines in physical function, as assessed by simple objective measures of muscle strength (eg, grip strength) and physical performance (eg, walking speed and chair stand speed), are pervasive features of older age and can result in decreased autonomy of mobility and of carrying out daily activities, and in reduced cognitive abilities.[4,5] This decline ultimately contributes to loss of independence, which is among the most feared aspects of ageing.[6] Poor physical function is also estimated to have annual health-care costs of £2·5 billion in the UK[7] and US$18·5 billion in the USA.[8] Thus, weakness and impaired physical performance in older individuals pose substantial personal and socioeconomic challenges, and identifying factors related to poor physical function is of great interest.

Oral health is an important aspect of overall health and wellbeing;[9] however, poor oral health is prevalent in older adults.[10,11] Oral health is multifaceted, encompassing characteristics of the mouth and face, including teeth and periodontal (gum)-related issues (eg, tooth loss and periodontal disease), xerostomia (dry mouth), difficulty in chewing, and oral diseases. Adverse oral health can affect diet quality[12] and is also associated with chronic low-grade inflammation and diseases (including, but not limited to, cardiovascular disease and diabetes) that can impede physical function.[13,14] Older adults with oral health problems are more likely to have poor physical function and functional limitations compared with adults with good oral health, but evidence for these associations has been derived mainly from cross-sectional analyses.[15–18]

Research in context

Evidence before this study

Evidence from previous research suggests a potential association between oral health and physical function in older adults. However, data from longitudinal studies examining the prospective associations between oral health and decline in muscle strength and physical performance are scarce, conflicting, and based on limited markers of oral health or muscle strength and performance.

Added value of this study

To the best of our knowledge, this is the first study to examine the association between multiple markers of oral health and decline in both muscle strength and physical performance in later life. We examine these associations in two large prospective cohorts from the UK and USA with a comprehensive set of both objective and self-rated oral health markers, together with changes in oral health over approximately 8 years. Therefore, this study provides novel information regarding the longitudinal association of oral health with decline in physical functioning in older adults.

Implications of all the available evidence

This study suggests that oral health problems, particularly self-reported dry mouth, and periodontal disease, could be important indicators of decline in muscle strength and performance in later life. Identifying and treating oral health problems in older adults could help preserve physical function in this population—a key determinant of independence and quality of life. However, further studies are needed to understand the potential causal relationship.

Longitudinal associations between oral health and muscle strength and physical performance have been studied to a much lesser extent. Tooth loss has been associated with deteriorated gait speed[13,19,20] and periodontal disease with a decline in hand grip strength,[21] supporting the notion of a potential important relationship between oral health and physical function. Nonetheless, few previous studies have included multiple measures of oral health, or physical performance, and, to our knowledge, none have investigated changes in both variables simultaneously. Consequently, the aim of this study was to examine longitudinal associations between comprehensive markers of oral health, including changes in oral health over time, and physical function and decline in muscle strength and physical performance. We use two cohort studies of older adults in the UK and the USA, both of which consist of mostly community-dwelling older adults and have complementary data on a range of measures of oral health and physical function in later life.

Methods

The British Regional Heart Study

The British Regional Heart Study (BRHS) is an ongoing cohort study initially established in 1978–80, and which includes 7735 British men (aged 40–59 years at the time of enrolment) from 24 towns.[22] The BRHS cohort underwent a physical examination in 2010–12, serving as baseline for the present analyses, and a follow-up examination in 2018. An overview of the BRHS cohort participants and timepoints of follow-up used in the present analysis are shown in figure 1. Between July, 2010, and June, 2012, when members of the cohort were aged 71–92 years, 1722 of 3137 men who were still alive, residing in the UK, and were contactable (55% response rate) attended a physical examination, including oral health checks. Between February, 2010, and December, 2012, 2137 of 3137 men (68% response rate) completed a detailed questionnaire, which assessed factors in five broad domains: (1) overall health, diagnoses, and self-reported symptoms; (2) socioeconomic factors; (3) health behaviours; (4) anthropometry and nutrition; and (5) physical function. A follow-up examination of the cohort (aged 78–98 years) was done between August, 2018, and January, 2019, and was attended by 667 of 1633 men who were still living in the UK and were contactable (41% response rate), and 1009 of 1633 men (62% response rate) completed a postal questionnaire between July and December, 2018. Ethical approval was granted by the National Research Ethics Service Committee, London, UK. All men provided written informed consent to participate in the investigations, which were done in accordance with the Declaration of Helsinki.

The Health, Aging and Body Composition Study

The Health, Aging and Body Composition (Health ABC) Study is a prospective cohort study in which 3075 White and African American men and women, aged 70–79 years at the time of enrolment, were recruited from Memphis, TN, and Pittsburgh, PA, in the USA. White participants were randomly sampled from Medicare enrollees living in Memphis or Pittsburgh, whereas African American participants were selected from neighbourhoods in designated zip code areas in Memphis and Pittsburgh.[23] Only individuals who were able to walk 0·25 miles or climb 10 steps without any difficulty were recruited to the study. Figure 1 shows an overview of the Health ABC Study participants and timepoints of follow-up used in the present analysis. In year 2 (for each participant; between February, 1998, and June, 1999), 2998 of 3040 surviving participants still enrolled in the study (99% response rate), aged 71–80 years, completed physical assessments, provided blood samples, and completed questionnaires, which assessed health status, symptoms and medications, pyschosocial and behavioural factors, anthropometry, and physical functioning. A subset of participants (1975 of 3040) underwent an oral health assessment, and this timepoint was used as the baseline for the

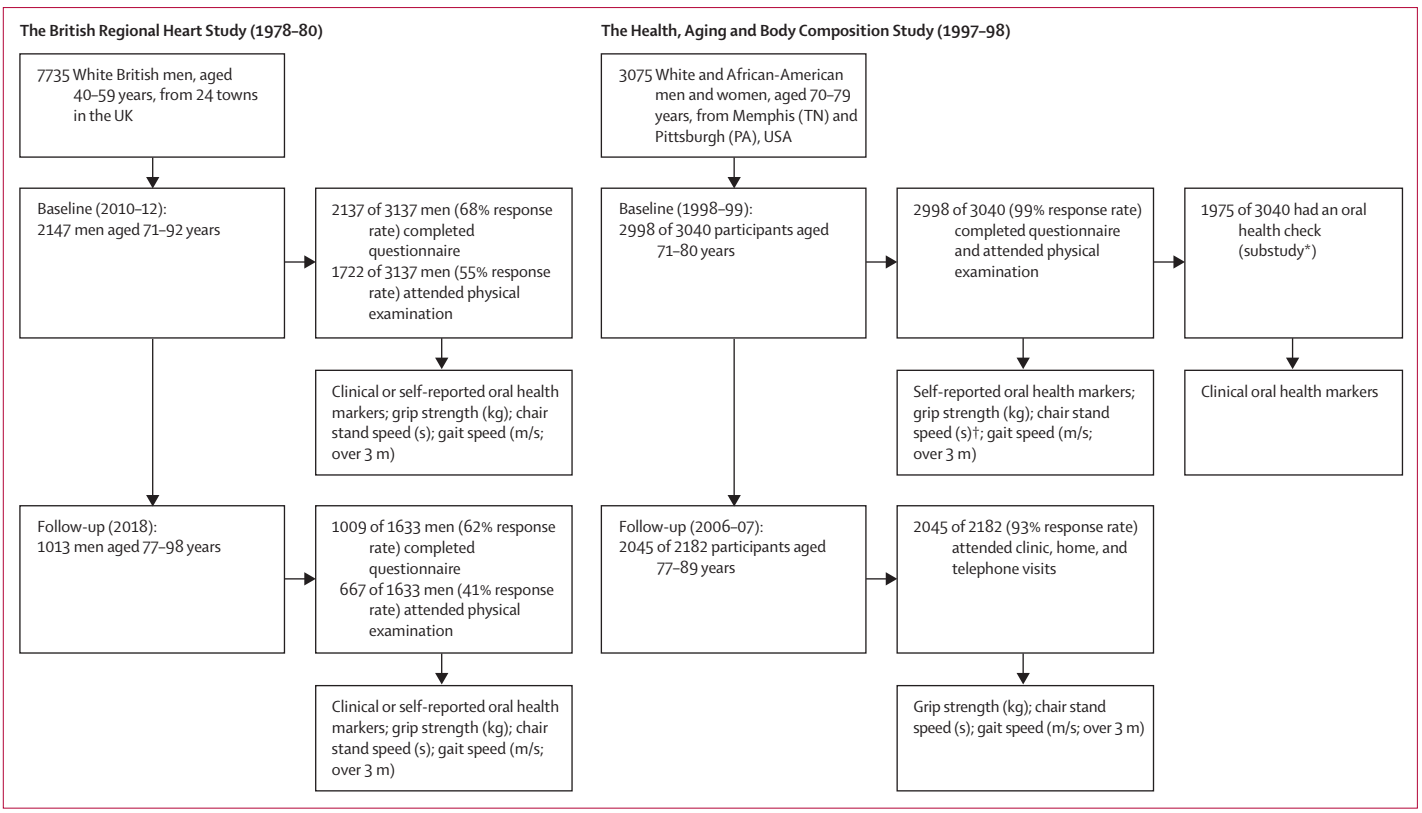

Figure 1: **Flow chart of the British Regional Heart Study and the Health, Aging and Body Composition Study participants and follow-up included in the current study**
*Clinical oral health markers were only collected in a subset of the Health, Aging and Body Composition study participants. †Chair stand test was not assessed in 1998–99, so data on chair stand test from 1997–98 were used instead.

present analyses. In year 10 (for each participant; between June, 2006, and June, 2007), data from an assessment of the cohort were used for follow-up of physical function in the present analyses. This assessment consisted of clinic visits, home visits, and telephone calls, which were completed by 2045 of 2182 surviving participants still enrolled (93% response rate) aged 77–89 years. All participants provided written informed consent. Ethical approval was granted by the University of Pittsburgh, the University of Tennessee, Memphis, the University of California San Francisco, and the US National Institutes of Health.

Oral health

In both studies, clinical measures of oral health were evaluated through an oral examination, and self-reported oral health was assessed through questionnaires. Clinical measures of oral health comprised a count of remaining natural teeth and a periodontal disease assessment (ie, loss of attachment and pocket depth in participants with natural teeth). In the BRHS, as part of the physical examination that took place in 2010–12, a brief periodontal assessment was done in six index teeth (one per sextant of the mouth).[10,24] In year 2 of the Health ABC Study, a full mouth assessment of periodontal disease was done by a dental hygienist or a periodontist.[11] Further details of the periodontal assessment and validity have been reported previously.[10,11,24] Questionnaires administered in both studies included self-reported oral health measures, such as overall self-rated oral health as excellent, good, fair, or poor; difficulty eating or chewing due to mouth, teeth, or denture issues, or sensitivity to hot or cold foods, or sweets; and dry mouth (via the Xerostomia Inventory scale in the BRHS,[25] and via a single question [does your mouth feel dry when eating?] in the Health ABC Study).[26] Oral health markers were categorised on the basis of previous studies, including those from the BRHS and Health ABC Study.[24] Clinical oral health markers were characterised as the number of natural teeth (as a three-level variable: 0, 1–20, and 21 or more teeth) present. Periodontal status was assessed in participants who were dentate and was classified as 0–20% and more than 20% of sites with a pocket depth of more than 3·5 mm (BRHS) or more than 3 mm (Health ABC Study), and loss of attachment of more than 5·5 mm (BRHS) or 3 mm or more (Health ABC Study). The cutoff points for periodontal measures were based on assessments made in both cohorts and distribution of measures in the two cohorts; the same cutoff points have been previously used in these two cohort studies.[11,16] Self-rated oral health was grouped into excellent or good versus fair or poor; dry mouth symptoms were categorised as 0 or 1 or more

symptoms (BRHS), or as yes or no (Health ABC Study); and difficulty eating or chewing was binary (yes or no) for both the studies. In both studies, a composite (or cumulative) measure of the presence of any oral health problems was created and used as a global assessment of the extent of poor oral health. This measure was based on the combination of oral health problems, including number of natural teeth (fewer than 21 teeth); fair or poor self-rated oral health; dry mouth; and difficulty eating or chewing and sensitivity to hot or cold foods, or sweets (BRHS), or limiting food intake because of gum problems (Health ABC Study). This composite measure was categorised as 0, 1, or 2 or more oral health problems.

Changes in oral health

In the BRHS only, oral health was measured again at the follow-up physical examination in 2018, using the same questionnaire and a full examination of the mouth (for tooth count and periodontal status) by a dental hygienist. From these data, changes from baseline to follow-up were calculated for oral health markers, including number of natural teeth (dentition), self-rated oral health, difficulty eating, and dry mouth. The variables were trichotomised as sustained good or improved, sustained poor, and deteriorated oral health. Deteriorated oral health was based on changes in different markers of oral health, namely deteriorated dentition (based on changing from having functional dentition [21 or more teeth] to having fewer than 21 teeth, or changing from 1–20 to zero teeth at the follow-up exam); deteriorated self-rated oral health (based on poor or fair self-rated oral health at follow-up but not at baseline); increased difficulty eating (based on difficulty eating at follow-up but not baseline); and worsened dry mouth (based on one or more additional dry mouth symptoms at follow-up). Since periodontal status at follow-up was based on examination of all teeth, rather than of six index teeth, which was done at baseline, a comparison of changes in periodontal measures could not be done. The Health ABC Study had oral health measures only at baseline and therefore, information on changes in oral health were not available in this cohort.

Muscle strength and physical performance

Muscle strength was assessed by grip strength (via the Jamar Hydraulic Hand Dynamometer; Jamar, Loughborough, UK [BRHS]; Illinois, USA [Health ABC Study]). In the BRHS, three measurements were taken for each hand, and in the Health ABC Study, two measurements were taken for each hand, with the highest score used for the analysis. Physical performance was calculated as the time (in seconds) to perform five serial chair stands in succession and gait speed (m/s); the use of hands or a walking aid was permitted, if necessary. Gait speed was calculated from the time required to walk 3 m at a normal pace (BRHS), or 20 m at a normal pace (Health ABC Study).[27] These physical assessments were made using the same protocol at baseline and follow-up in both studies; however, in the Health ABC Study, chair stand test results were available only at year 1 (1997–98), and were used as baseline for the analysis.

Covariates

In both studies, information on sociodemographic factors, behavioural factors (eg, smoking history and physical activity), and health-related information (ie, history of cardiovascular disease, diabetes, activities of daily living, and prescribed medications) was available from questionnaires. Socioeconomic position was based on occupational social class derived from the longest-held occupation when participants entered the study in the BRHS,[10] and according to years of education in the Health ABC Study.[16] In the BRHS, smoking history was defined as being a current smoker, a long-term ex-smoker (gave up smoking before 1983), a recent ex-smoker (gave up smoking after 1983), or having never smoked;[24] alcohol intake was established from the available data on frequency and amount of alcohol consumption and classified as moderate to heavy, occasional, or non-drinkers; and physical activity was assessed from a short questionnaire of time spent on walking, recreational activities, and sport or exercise and was characterised as moderate to vigorous activity, occasional to light activity, and inactivity.[28] In the Health ABC Study, smoking status was classified as being a current smoker, former smoker, and having never smoked; and physical activity was assessed using a modified leisure-time physical activity questionnaire,[29] and expressed as total calories consumed per kilogram per week; alcohol consumption was not assessed in year 2 of the Health ABC Study. In both studies, information on activities of daily living disability (yes or no) was available as previously described.[16] BMI was assessed as part of the physical examinations. Plasma concentrations of IL-6 (a marker of inflammation) were measured in blood samples collected during the physical examinations in both studies.

Statistical analysis

Descriptive characteristics are presented as means and standard deviations for continuous variables and percentages for categorical variables. The analytical sample included participants of the BRHS and Health ABC Study that attended both the physical examinations at baseline and follow-up in the two studies. All analyses were done separately for the BRHS and Health ABC Study.

A series of ANCOVA regression models were undertaken to assess the relations of the different oral health markers at baseline with the means of each of the three physical function measures at follow-up (ie, grip strength, chair stand speed, and gait speed). Models were adjusted for the score of the respective physical function measure at baseline and other confounding

	BRHS (n=612)	Health ABC Study (n=1572)
Sex		
Men	612 (100%)	724 (46·1%)
Women	0	848 (53·9%)
Age, years	77 (4)	74 (3)
BMI, kg/m²	27·1 (3·6)	27·4 (4·8)
Number of natural teeth	17 (9)	18 (9)
Use of dentures		
Yes	335 (54·7%)	482 (30·7%)
No	268 (43·8%)	1072 (68·2%)
Unknown	9 (1·5%)	18 (1·2%)
Occupational social class (manual)	247 (40·4%)	Not assessed
Smoking status		
Current smoker	16 (2·6%)	109 (6·9%)
Former smoker	334 (54·8%)	693 (44·1%)
Never smoked	260 (42·5%)	767 (48·8%)
Missing data	2 (0·3%)	3 (0·2%)
Moderate to heavy alcohol consumption	29 (4·7%)	Not assessed
Physically inactive	63 (10·3%)	244 (15·5%)*
History of cardiovascular disease	100 (16·3%)	57 (3·6%)
History of diabetes	96 (15·7%)	67 (4·3%)
Taking one or more medications with a dry mouth side-effect	229 (37·4%)	912 (58·0%)
Plasma IL-6 concentration, pg/mL	3·7 (4·1)	3·1 (3·3)
Problems with activities of daily living	52 (8·5%)	230 (14·6%)
Race		
White	592 (96·7%)	1043 (66·3%)
African American	..	529 (33·7%)
Other or not recorded	20 (3·3%)	..
Education level attained		
High school or lower	Not assessed	304 (19·3%)
High school graduate	Not assessed	501 (31·9%)
Post-high school	Not assessed	765 (48·7%)
Data missing	Not assessed	2 (0·1%)

Data are n (%) or mean (SD). BRHS=The British Regional Heart Study. Health ABC Study=The Health, Aging and Body Composition Study. *Based on the lowest quintile of phyical activity in kcal/kg per week.

Table 1: **Baseline characteristics of participants in the BRHS (2010–12) and Health ABC Study (1998–99) included in this analysis**

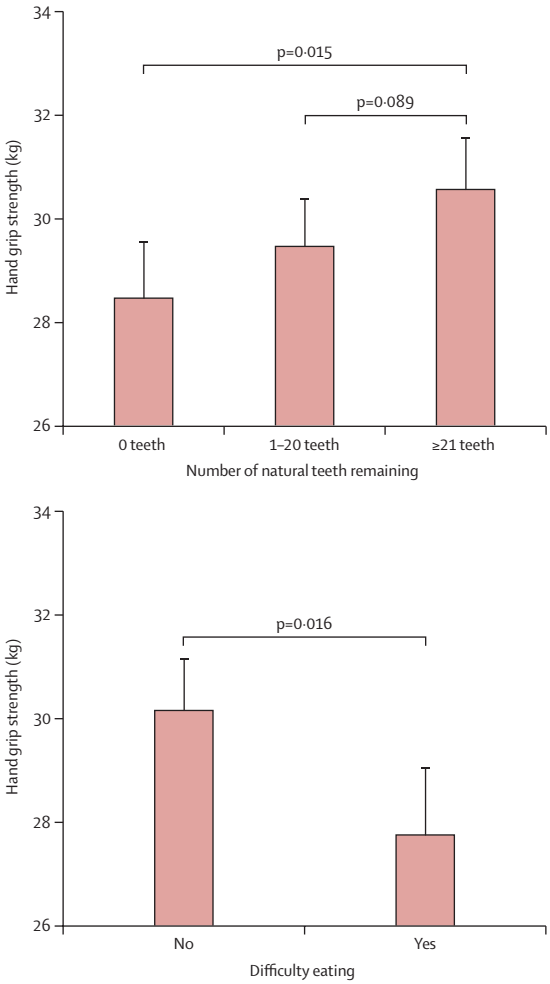

Figure 2: **Adjusted mean hand grip strength at follow-up (2018) according to oral health problems at baseline (2010–12) in the British Regional Heart Study**

ANCOVA adjusted for baseline grip strength, age, socioeconomic position, smoking, alcohol, physical activity, BMI, history of cardiovascular disease and diabetes, and disability.

factors. Dunnett multiple post-hoc comparisons were used in the models,[30] with participants without oral health problems as the reference group. Multivariate logistic regression models were done to examine the associations between the different oral health markers at baseline with the decline in each of the three physical function measures as the dependent variables. For both studies, a score for decline in physical function was estimated as the change at the follow-up period (calculated as the difference between baseline and follow-up measure). Odds ratios (ORs) and 95% CIs were obtained for the score of decline in physical function measures according to each of the different oral health markers (with participants without oral health problems as the reference). A binary outcome of decline in physical function was created, in which the decline was defined as being in the top tertile with the largest negative change.[31] In the BRHS, physical function equated to a decrease in grip strength of more than 7 kg, an increase in chair stand speed of more than 1·26 s, and a decrease in gait speed of more than 0·24 m/s. In the Health ABC Study, decline in physical function equated to a decrease in grip strength of more than 10 kg, an increase in chair stand speed of more than 3·51 s, and a decrease in gait speed of more than 0·22 m/s. Similarly, in the BRHS sample, logistic

	Number of participants (n=612)	Decline in grip strength (>7 kg decrease)		Decline in chair stand speed (>1·26 s increase)		Decline in gait speed (>0·24 m/s decrease)	
		Odds ratio (95% CI)	p value (*vs* reference)	Odds ratio (95% CI)	p value (*vs* reference)	Odds ratio (95% CI)	p value (*vs* reference)
Number of natural teeth remaining							
0	80 (13·1%)	1·55 (0·85–2·84)	0·15	1·19 (0·65–2·19)	0·61	1·05 (0·58–1·89)	0·88
1–20	244 (39·9%)	1·50 (0·98–2·30)	0·064	0·86 (0·55–1·33)	0·53	0·97 (0·64–1·47)	0·88
≥21	268 (43·8%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Unknown or not measured	20 (3·3%)	..	..	..	..	..	..
Pocket depth (percentage of sites that are >3·5 mm deep)							
0–20	361 (59·9%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
>20	132 (21·6%)	0·94 (0·57–1·53)	0·80	1·60 (0·99–2·73)	0·055	2·40 (1·53–3·76)	0·0001
Unknown or not measured	119 (19·4%)	..	..	..	..	..	..
Loss of attachment (percentage of sites that are >5·5 mm deep)							
0–20	394 (64·4%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
>20	99 (16·2%)	1·06 (0·62–1·80)	0·84	1·03 (0·60–1·76)	0·94	1·18 (0·71–1·96)	0·52
Unknown or not measured	119 (19·4%)	..	..	..	..	..	..
Difficulty eating							
No	390 (63·7%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Yes	43 (7·0%)	1·74 (0·84–3·61)	0·14	1·74 (0·84–3·61)	0·59	0·94 (0·43–2·03)	0·87
Unknown or not measured	179 (29·3%)	..	..	..	..	..	..
Self-rated oral health							
Good or excellent	408 (66·7%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Fair or poor	186 (30·4%)	1·04 (0·68–1·59)	0·85	1·11 (0·72–1·71)	0·54	0·84 (0·55–1·27)	0·40
Unknown or not measured	18 (2·9%)	..	..	..	..	..	..
Dry mouth symptoms*							
0	239 (39·1%)	1 (ref)	..	1 (ref)	..	1 (ref)	
≥1	353 (57·7%)	1·50 (1·00–2·25)	0·048	0·83 (0·55–1·24)	0·35	1·21 (0·82–1·79)	0·33
Unknown or not measured	20 (3·3%)	..	..	..	..	..	..
Cumulative oral health problems*†							
0	157 (25·7%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
1	270 (44·1%)	1·07 (0·65–1·74)	0·80	0·65 (0·40–1·05)	0·075	0·76 (0·48–1·20)	0·24
≥2	185 (30·2%)	1·78 (1·06–2·99)	0·027	0·70 (0·41–1·18)	0·18	0·87 (0·53–1·44)	0·59

Data are n (%) or odds ratio (95% CI), unless otherwise stated. Adjusted for baseline age, socioeconomic position, smoking, alcohol, physical activity, BMI, history of cardiovascular disease and diabetes, and disability. A p value of 0·05 or less was considered statistically significant. *Adjusted for medications with dry mouth as a recognised side-effect. †Fewer than 21 teeth, one or more dry mouth symptoms, difficulty eating, and sensitivity to hot or cold foods, or sweets.

Table 2: **Associations between oral health at baseline (2010–12) and decline in physical function over a period of 7·5 years in the British Regional Heart Study**

regression models were done to examine the associations of changes in different oral health markers over the follow-up period with the decline in each of the three physical function measures as the dependent variables. The Health ABC Study did not have data on follow-up measures of oral health.

Full adjustments were made for baseline age, socioeconomic position, alcohol consumption, smoking status, physical activity, BMI (continuous), history of cardiovascular disease and diabetes, and disability in the BRHS; and for sex, race, education, smoking status, physical activity, BMI (continuous), history of cardiovascular disease and diabetes, and disability in the Health ABC Study. Models for dry mouth and cumulative oral health problems were also adjusted for medications with dry mouth as a recognised side-effect. Covariates were tested for correlation before they were entered in the models. Fully adjusted associations that were significant were further adjusted for baseline IL-6 as a continuous variable. All analyses were done with SAS version 9.4 and were restricted to individuals with data at both timepoints.

Role of the funding source
The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

In the BRHS, 612 men, with a mean age of 77 years (SD 4) at baseline (2010–12), attended physical examinations at both timepoints. In the Health ABC Study, physical examination data, from either clinic or home visits, were available for 1572 participants (848 [53·9%] women and 724 [46·1%] men) at both baseline (mean age 74 years [SD 3]) and at year 10 (follow-up). Baseline characteristics, including sociodemographic, behavioural, and health factors of participants in the BRHS and Health ABC Study are presented in table 1.

The adjusted means for measures of physical function at follow-up according to oral health at baseline in the BRHS cohort are shown in figure 2. Participants with no natural teeth compared with those with functional dentition (ie, at least 21 teeth) had lower adjusted mean grip strength at follow-up (28·5 kg *vs* 30·6 kg; p=0·015). Participants with self-reported difficulty eating compared with those without also had lower adjusted mean grip strength at follow-up (27·8 kg *vs* 30·2 kg; p=0·016). Other oral health markers (ie, periodontal disease, dry mouth, and self-rated oral health) did not show any significant difference in mean physical function scores (data not shown).

ORs for the associations between markers of oral health at baseline and decline in physical function measures over the follow-up period of the BRHS are shown in table 2. Having one or more dry mouth symptoms (adjusted OR 1·50 [95% CI 1·00–2·25]) and two or more cumulative oral health problems (1·78 [1·06–2·99]) compared with none was associated with a significant decline in grip strength. Periodontal status measured as pocket depth was associated with decline in gait speed (adjusted OR 2·40 [95% CI 1·53–3·76]). Further adjustment for IL-6 attenuated the association of difficulty eating with adjusted mean grip strength; all other associations remained significant (data not shown).

The adjusted means for measures of physical function at follow-up according to oral health at baseline in the Health ABC Study are shown in figure 3. Participants who had no teeth compared with those with functional dentition had lower adjusted mean gait speed at follow-up (0·93 *vs* 0·98 m/s; p=0·026). Similarly, participants with self-rated oral health of fair or poor compared with good or excellent (0·97 *vs* 1·00 m/s; p=0·0094) and participants with one oral health problem compared with those with no health problems (0·98 *vs* 1·01 m/s; p=0·011) had lower adjusted mean gait speed at follow-up. Other oral health markers (periodontal disease, dry mouth, and difficulty eating) did not show any significant difference in mean physical function scores (data not shown).

ORs for the associations between markers of oral health and decline in physical function over time are

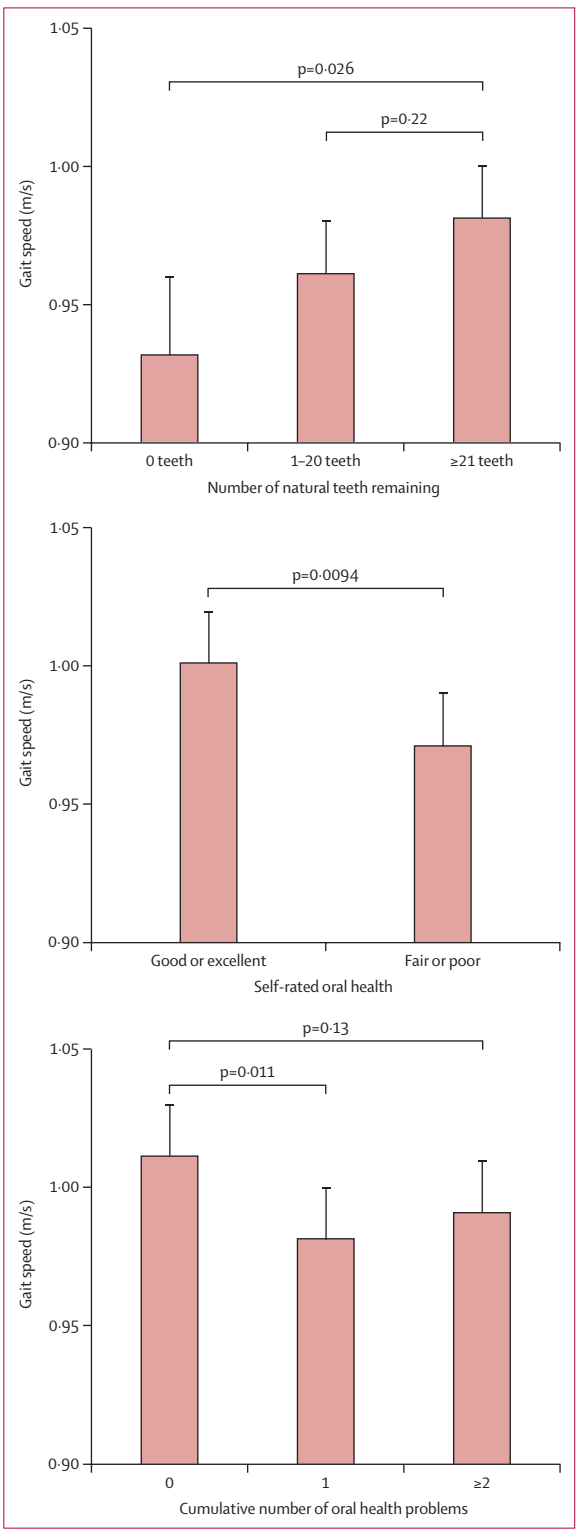

***Figure 3*: Adjusted mean gait speed at follow-up (2006–07) according to oral health problems at baseline (1998–99) in the Health, Aging and Body Composition Study**
ANCOVA adjusted for baseline gait speed, age, education level, smoking, physical activity, BMI, history of cardiovascular disease and diabetes, and disability.

	Number of participants (n=1572)	Decline in grip strength (>10 kg decrease)		Decline in chair stand speed (>3·51 s increase)		Decline in gait speed (>0·22 m/s decrease)	
		Odds ratio (95% CI)	p value (*vs* reference)	Odds ratio (95% CI)	p value (*vs* reference)	Odds ratio (95% CI)	p value (*vs* reference)
Number of natural teeth remaining							
0	96 (6·1%)	0·65 (0·36–1·18)	0·16	0·90 (0·49–1·63)	0·51	1·11 (0·63–1·93)	0·64
1–20	435 (27·7%)	1·07 (0·79–1·43)	0·67	0·90 (0·65–1·34)	0·72	1·08 (0·80–1·45)	0·73
≥21	600 (38·2%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Unknown or not measured	441 (28·1%)	..	..	..	..	..	..
Pocket depth (percentage of sites that are >3 mm deep)							
0–20	326 (20·7%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
>20	366 (23·3%)	1·06 (0·69–1·65)	0·78	0·99 (0·67–1·46)	0·96	0·80 (0·55–1·16)	0·23
Unknown or not measured	880 (56·0%)	..	..	..	..	..	..
Loss of attachment (percentage of sites that are >3 mm deep)							
0–20	264 (16·8%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
>20	427 (27·2%)	0·76 (0·53–1·08)	0·12	0·94 (0·64–1·37)	0·73	0·85 (0·59–1·23)	0·39
Unknown or not measured	881 (56·0%)	..	..	..	..	..	..
Difficulty eating							
No	1264 (80·4%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Yes	279 (17·8%)	1·24 (0·91–1·68)	0·17	0·87 (0·63–1·21)	0·42	0·96 (0·71–1·30)	0·77
Unknown or not measured	29 (1·8%)	..	..	..	..	..	..
Self-rated oral health							
Good or excellent	1109 (70·5%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Fair or poor	426 (27·1%)	1·18 (0·91–1·54)	0·22	0·83 (0·62–1·12)	0·23	1·27 (0·98–1·66)	0·08
Unknown or not measured	37 (2·4%)	..	..	..	..	..	..
Dry mouth symptoms*							
No	1487 (94·6%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Yes	50 (3·2%)	0·63 (0·30–1·31)	0·21	2·45 (1·14–5·27)†	0·021	1·36 (0·72–2·57)	0·34
Unknown or not measured	35 (2·2%)	..	..	..	..	..	..
Cumulative oral health problems*†							
0	500 (31·8%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
1	735 (46·8%)	0·84 (0·64–1·10)	0·20	0·86 (0·64–1·14)	0·29	1·12 (0·86–1·47)	0·40
≥2	319 (20·3%)	0·96 (0·98–1·35)	0·81	0·88 (0·61–1·27)	0·48	0·99 (0·70–1·40)	0·96
Unknown or not measured	18 (1·1%)	..	..	..	..	..	..

Data are n (%) or odds ratio (95% CI), unless otherwise stated. Adjusted for baseline age, education level, race, sex, smoking, physical activity, BMI, history of cardiovascular disease and diabetes, and disability. A p value of 0·05 or less was considered statistically significant. *Adjusted for medications with dry mouth as a recognised side-effect. †Fewer than 21 teeth, dry mouth when eating, difficulty eating or chewing, and reducing food intake because of gum problems.

Table 3: **Associations between oral health at baseline (1998–99) and decline in physical function over a period of 7·9 years in the Health, Aging and Body Composition Study**

presented in table 3. Self-reported dry mouth was associated with a decline in chair stand speed (adjusted OR 2·45 [95% CI 1·14–5·27]). These associations did not change with further adjustment for baseline IL-6 (data not shown).

Participants with sustained poor dentition (1–21 or no natural teeth at both timepoints) compared with those with sustained good dentition had lower adjusted mean grip strength at follow-up (29·3 kg *vs* 30·6 kg; p=0·04), but changes in other oral health variables did not show any significant difference in mean physical function scores (data not shown). ORs for associations between changes in oral health (baseline to follow-up) and decline in physical function measures in the BRHS are shown in table 4. Deteriorated dentition (adjusted OR 2·34 [95% CI 1·20–4·46]) and deteriorated difficulty eating (2·41 [1·04–5·60]) were associated with declines in chair stand speed.

	Number of participants (n=612)	Decline in grip strength (>7 kg decrease)		Decline in chair stand speed (>1·26 s increase)		Decline in gait speed (>0·24 m/s decrease)	
		Odds ratio (95% CI)	p value (*vs* reference)	Odds ratio (95% CI)	p value (*vs* reference)	Odds ratio (95% CI)	p value (*vs* reference)
Dentition							
Sustained good	210 (34·3%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Sustained poor	301 (49·2%)	1·49 (0·95–2·33)	0·81	1·13 (0·72–0·79)	0·57	1·11 (0·72–1·71)	0·64
Deteriorated	66 (10·8%)	0·88 (0·43–1·79)	0·72	2·34 (1·20–4·46)	0·012	1·53 (0·81–2·91)	0·19
Unknown or not measured	35 (5·7%)	..	..	..	..	..	..
Self-rated oral health							
Sustained good or excellent	397 (64·9%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Sustained fair or poor	110 (18·0%)	0·77 (0·45–1·32)	0·34	1·30 (0·81–2·29)	0·25	0·87 (0·52–1·46)	0·60
Deteriorated	66 (10·8%)	1·21 (0·65–2·22)	0·55	1·21 (0·64–2·29)	0·55	1·10 (0·60–2·03)	0·75
Unknown or not measured	39 (6·4%)	..	..	..	..	..	..
Difficulty eating							
Sustained good or improved	378 (61·8%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Sustained poor	19 (3·1%)	1·56 (0·57–4·30)	0·38	0·49 (0·15–1·67)	0·26	1·11 (0·38–3·26)	0·84
Deteriorated	34 (5·6%)	0·60 (0·23–1·53)	0·28	2·41 (1·04–5·60)	0·041	0·45 (0·17–1·16)	0·10
Unknown or not measured	181 (29·6%)	..	..	..	..	..	..
Dry mouth symptoms*							
Sustained good or improved	190 (31·0%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Sustained poor	210 (34·3%)	1·12 (0·70–1·79)	0·64	0·71 (0·44–1·16)	0·13	0·87 (0·55–1·36)	0·53
Deteriorated	182 (29·7%)	0·97 (0·60–1·58)	0·91	0·94 (0·58–1·54)	0·83	0·73 (0·46–1·18)	0·20
Unknown or not measured	30 (4·9%)	..	..	..	..	..	..

Data are n (%) or odds ratio (95% CI), unless otherwise stated. Adjusted for baseline age, socioeconomic position, smoking, alcohol, physical activity, BMI, history of cardiovascular disease and diabetes, and disability. A p value of 0·05 or less was considered statistically significant. *Adjusted for medications with dry mouth as a recognised side-effect.

Table 4: **Associations between changes in oral health and decline in physical function over a period of 7·5 years in the British Regional Heart Study**

Discussion

In our longitudinal study of two cohorts of community-dwelling older adults from the UK and the USA, tooth loss, cumulative and self-reported markers of oral health (eg, difficulty eating), and self-rated oral health were associated with weaker grip strength and slower gait speed. Moreover, dry mouth and periodontal pocket depth were associated with a greater decline (ie, the worst tertile for decline) in grip strength, chair stand speed, and gait speed. To the best of our knowledge, this is the first study to investigate changes in oral health and changes in physical function simultaneously. Our findings show that deteriorated dentition and difficulty eating accompany decline in physical performance at older ages. Together, these findings provide evidence that poor oral health is associated with reduced muscle strength and physical performance in later life.

We found that having no natural teeth compared with functional dentition (at least 21 teeth) was associated with having weaker grip strength in the BRHS and slower gait speed in the Health ABC Study. Moreover, mean grip strength and gait speed of participants with no teeth were below cutoffs used to identify other age-related syndromes, such as sarcopenia and disability.[32,33] Our findings support reports from studies showing that complete tooth loss is associated with slower walking speed.[13,20] Although some studies have shown that those with more remaining teeth have higher grip strength, at least cross-sectionally, the relationship between tooth loss and grip strength is inconsistent,[21,34–36] which was apparent in the two cohorts in the current study. This heterogeneity in findings between studies might relate to differences in strategies for dental management of participants with small numbers of teeth (eg, use of dentures) or differences in study designs. In this Article, we report that deterioration of dentition—ie, losing functional dentition or becoming edentulous (having no natural teeth)—was associated with decline in chair stand speed. There are at least two pathways through which poor oral health might be causally linked with reduced physical function. Advanced

oral disease, and its associated systemic inflammation, could have adverse effects on physical function directly,[37] or through effects on chewing ability, leading to inadequate nutritional intake; poor oral health could affect physical function indirectly.[38,39] In the current study, although adjustment for baseline IL-6 did not change the results, residual confounding remains a possibility due to other markers of inflammation or long-term measures of inflammation that were not taken into account. This contrasts with a previous study[13] that found that the association between tooth loss and accelerated decline in walking speed was no longer significant after adjustment for inflammation (in that case, C-reactive protein). In another study,[40] non-denture users with fewer than 20 natural teeth had weaker grip strength compared with those with more than 20 teeth, and poor nutritional intake explained more than 30% of this relationship. Although we did not adjust for dietary intake in the current study, we did adjust for BMI, which is an important clinical parameter of malnutrition (undernutrition).[41] Nonetheless, we cannot exclude the possibility that other dietary factors, such as intake of fruit, vegetables, and protein, that are known to be affected by tooth loss and difficulty in chewing, could affect nutrient intake, and therefore be responsible, indirectly, for the observed relationship between poor oral health and decline in physical function; these factors should be examined in future studies.[39,42]

In the current study, periodontal pocket depth (a measure of current periodontal disease) was associated with decline in chair stand and gait speed in the BRHS cohort. In support of these findings, periodontal disease has been associated with decline in grip strength[21] and physical frailty in later life.[43,44] Periodontal disease is an inflammatory disease that could lead to tooth loss.[45] The underlying systemic inflammation accompanying more acute periodontal disease (ie, before tooth loss) has been associated with poor physical fitness and capacity[46,47] and with a decline in lower extremity mobility,[48] which might result in reduced physical performance over time. Additionally, periodontal disease might be related to oral microbiome dysbiosis, which might also be implicated in decline in physical performance via systemic inflammatory or immunological responses to oral microbes.[49,50]

In addition to associations with clinical oral health markers, we also found associations between measures of physical function and other simple self-rated oral health markers, including self-rated oral health and dry mouth. Self-rated fair or poor oral health was associated with lower gait speed, which aligns with findings from our previous cross-sectional study.[16] Additionally, dry mouth was associated with decline in grip strength and chair stand speed. Dry mouth is a particularly prevalent oral health problem in older adults (often occurring as a side-effect of medication for chronic age-related diseases),[51] which might lead to ulceration and inflammation of oral mucosa and can cause difficulties chewing and swallowing and dental diseases.[52,53] In accordance with our findings, self-rated measures of oral dryness, perhaps more so than objective markers, have been associated with slow gait speed, mobility limitations, and physical frailty.[15,24,54] Notably, self-rated oral health and dry mouth are closely related to general health status, medication use, and psychological factors; therefore the relationship between these markers and physical function is likely to be complex.[52,55] We also found that participants with self-reported difficulty eating had weaker grip strength, in agreement with previous findings,[15] whereas those who reported difficulty eating at follow-up but not at baseline had higher odds of decline in chair stand speed, supporting that nutrition might, at least in part, mediate these relationships. Difficulty eating was not associated with lower grip strength after adjustment for IL-6, which suggests that difficulty eating was related to pain and, subsequently, inflammation.[56] Therefore, other oral health factors, beyond periodontal diseases, might involve inflammatory processes with potential to contribute to decline of physical function. Additionally, having two or more cumulative oral health problems in the BRHS was associated with decline in grip strength, and one oral health problem (including mostly self-rated markers) in the Health ABC Study was associated with lower gait speed, but not decline in gait speed. These data highlight that oral health markers, which are relatively easy to assess, can be useful to identify individuals at risk of diminished physical performance, and subsequently frailty and disability, in later life. However, bidirectional associations between oral health and physical function should also be considered. Functional limitations and decline in physical function are likely to result in difficulties in maintaining adequate oral hygiene and accessing dental services, which in turn lead to worsening oral health.[57] Future studies should investigate these complexities, attempt to understand the causal pathways, and identify the mechanisms mediating these associations to provide a stronger evidence base for potential interventional targets.

One of the strengths of this study is that it provides evidence for the prospective associations of a comprehensive set of oral health problems with muscle strength and physical performance in two large cohorts of older people from the UK and USA. In addition, the detailed measures available in both cohorts allowed us to adjust for important confounders, whereas the BRHS allowed for analysis of contemporaneous changes in both oral health and physical function.

The study also has limitations. First, design features of both cohorts limit the generalisability of our findings. The BRHS consisted of White British men only and the Health ABC Study was restricted to include White and African American men and women living in Pittsburgh and Memphis, USA. However, both cohorts included two diverse populations of older adults from the community and were not restricted to those on dentist registries. By design, older individuals with disability were not recruited

to the Health ABC Study at baseline (1997–98). Consequently, the Health ABC Study cohort had higher gait speed at follow-up and a lower frequency of edentulism and dry mouth, indicating that these participants were healthier than those in the BRHS. Dry mouth in the Health ABC Study was based on a single-item question, which might not have fully captured the extent of dry mouth in this population. Furthermore, some oral health problems (eg, periodontal disease and dry mouth), gait speed measures (3 m *vs* 20 m), and socioeconomic position measures were assessed differently in the two studies. Lastly, despite adjusting for various confounders, we did not include information on the duration or severity of these factors in the models and other confounders, such as comorbidities. Therefore, the possibility of residual confounding cannot be excluded; similarly, no information was available for how and when participants lost their teeth. Our analyses were done in existing observational cohort studies, which might not have been adequately powered to test the associations presented. Nonetheless, the samples in both cohorts allowed us to test these associations in relatively comparable studies with unique data on oral health and physical function in very old ages, setting the basis to test these associations in future studies with larger sample sizes.

In summary, this investigation provides evidence from longitudinal studies that older individuals with oral health problems, including those that persist or worsen over time, have reduced physical function and greater decline in muscle strength and physical performance in later life. The findings suggest that objective and self-reported measures of poor oral health could be indicators of functional decline in older adults. Future research should aim to establish the underlying causal pathways and the mediators of these relationships to strengthen the evidence base on whether oral health interventions might help maintain better physical function in older age.

Contributors

RK, SER, SGW, AOP, PHW, JCM, RJW, YK, and LTL contributed to the study concept and design. SER, SGW, AOP, PHW, RJW, and LTL contributed to the acquisition of data. RK, GM, SER, and AOP had access to and verified all the underlying data. All authors contributed to the drafting and critical revision of the manuscript for important intellectual content, and to the analysis and interpretation of data. All authors have full access to all the data in the study and have final responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

Data for the British Regional Heart Study (BRHS) are available from https://www.ucl.ac.uk/british-regional-heart-study and data for the Health, Aging and Body Composition (Health ABC) Study are available from https://healthabc.nia.nih.gov/.

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