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Original Study

The Relationship of Oral Health with Progression of Physical Frailty among Older Adults: A Longitudinal Study Composed of Two Cohorts of Older Adults from the United Kingdom and United States

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A B S T R A C T

Objective: To investigate the prospective associations between oral health and progression of physical frailty in older adults.
Design: Prospective analysis.
Setting and Participants: Data are from the British Regional Heart Study (BRHS) comprising 2137 men aged 71 to 92 years from 24 British towns and the Health, Aging, and Body Composition (HABC) Study of 3075 men and women aged 70 to 79 years.
Methods: Oral health markers included denture use, tooth count, periodontal disease, self-rated oral health, dry mouth, and perceived difficulty eating. Physical frailty progression after ~8 years follow-up was determined based on 2 scoring tools: the Fried frailty phenotype (for physical frailty) and the Gill index (for severe frailty). Logistic regression models were conducted to examine the associations between oral health markers and progression to frailty and severe frailty, adjusted for sociodemographic, behavioral, and health-related factors.
Results: After full adjustment, progression to frailty was associated with dentition [per each additional tooth, odds ratio (OR) 0.97; 95% CI: 0.95–1.00], <21 teeth with (OR 1.74; 95% CI: 1.02–2.96) or without denture use (OR 2.45; 95% CI 1.15–5.21), and symptoms of dry mouth (OR ≥1.8; 95% CI ≥ 1.06–3.10) in the BRHS cohort. In the HABC Study, progression to frailty was associated with dry mouth (OR 2.62; 95% CI 1.05–6.55), self-reported difficulty eating (OR 2.12; 95% CI 1.28–3.50) and ≥2 cumulative oral health problems (OR 2.29; 95% CI 1.17–4.50). Progression to severe frailty was associated with edentulism (OR 4.44; 95% CI 1.39–14.15) and <21 teeth without dentures after full adjustment.
Conclusions and Implications: These findings indicate that oral health problems, particularly tooth loss and dry mouth, in older adults are associated with progression to frailty in later life. Additional research is needed to determine if interventions aimed at maintaining (or improving) oral health can contribute to reducing the risk, and worsening, of physical frailty in older adults.

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Worldwide there has been a rapid demographic transition resulting in an unprecedented growth of the aging population, with 16% of the population predicted to be 65 years or older by 2050.[1] Together with increased life expectancy, this has resulted in an important public health challenge: to maintain independent living, specifically by delaying or preventing frailty in older adults.[2,3] Frailty is a complex age-related syndrome that represents a dynamic progression from robustness to functional decline resulting in an elevated risk of adverse health outcomes, such as falls, disability, hospitalization, institutionalization, and mortality, and is a major health concern for older people, their families, and their carers.[4,5]

A recent review of studies has shown that objective and subjective markers of poor oral health are associated with frailty in older adults.[6] In addition, we have shown that oral health markers are associated with self-reported physical frailty in the British Regional Heart Study (BRHS).[7] There are reasons to expect that oral health may be related to frailty, given that oral health is implicated in microbiome dysbiosis, inflammatory/immunological status, and nutritional changes.[8–10] However, the aforementioned review demonstrates a paucity of longitudinal studies and few studies have examined whether oral health markers are associated with progression, or worsening, of frailty in older adults.[6] In one study, Horibe and colleagues[11] demonstrated an association between oral health and frailty progression, but they had limited oral health markers (including objective and subjective chewing ability) and, in common with other studies in this area, had a relatively short follow-up period. These limitations in the evidence base highlight the need for additional well-designed longitudinal studies, with longer follow-up periods and with comprehensive assessments of oral health markers, to examine the prospective associations between oral health with frailty in older adults.

Furthermore, most studies use the Fried frailty phenotype to characterize physical frailty.[6] Although the frailty phenotype has been used widely in epidemiological studies and is important for comparison with prior work,[12] there is no universal consensus in the operational criteria used to define physical frailty. An alternative tool is the Gill index, which characterizes severe frailty based on a composite measure of chair-stand and walking speed tests.[13] The Gill index has been used predominantly in the Health Aging and Body Composition (HABC) Study to characterize physical frailty and is more representative of functional measures that have been strongly associated with the progression of frailty to disability.[14–16] The HABC Study has detailed information on oral health measures that are similar to the BRHS. Therefore, we investigated whether oral health is prospectively associated with progression of frailty as measured by 2 different measures of frailty (the Fried frailty phenotype and the Gill index) in 2 cohorts of older adults in the United States and United Kingdom.

Methods

Data Source

The current study used data from the BRHS in the United Kingdom[17] and the HABC Study in the United States[18] to examine associations between poor oral health with frailty over ~8 years of follow-up.

The BRHS is an ongoing cohort study with a study population representative of British men, established in 1978 to 1980 and including 7735 British men (aged 40–59 years) from 24 towns.[19] The analysis in the current study used data from the BRHS physical examination in 2010–2012, which served as baseline, and the follow-up examination in 2018. In 2010–2012, when aged 71 to 92, 1722 men attended a physical examination including oral health measures (55% response rate) and 2137 completed a detailed questionnaire (68% response rate). A follow-up examination was conducted in 2018 that was attended by 667 men (41% response rate), and 1009 men (62% response rate) completed a questionnaire between July and December 2018, when aged 78 to 98 years. The physical examination included measures of anthropometry, physical function, and oral health, which was completed at both time points (2010–12 and 2018) by 612 men. The questionnaire included information related to socioeconomic, behavioral, and lifestyle factors, as well as current health and medical history, which was completed by 930 men at both time points. Ethical approval was provided by the National Research Ethics Service Committee, London. All men provided written informed consent to participate in the investigations, which were conducted in accordance with the Declaration of Helsinki.

The HABC Study is a prospective cohort study in which 3075 White and African American men and women, aged 70 to 79 years, were recruited. White participants were selected at random through Medicare, whereas African American participants were selected from neighborhoods with a zip code around Memphis and Pittsburgh.[18] Because the HABC Study was originally designed to examine incident mobility disability, only individuals who were able to walk 0.25 miles or climb 10 steps without difficulty were included in the study at baseline (https://healthabc.nia.nih.gov/). In year 2 (1998–1999; n = 2998), participants aged 71 to 80 years completed physical assessments, provided blood samples, completed questionnaires (response rate = 97.5%) and underwent an oral health assessment (n = 1975). This assessment acted as baseline for the current analysis and the year 10 (2006–2007; n = 2045) physical assessment was used for follow-up physical function. All participants provided written informed consent. Ethical approval was provided by University of Pittsburgh, University of Tennessee–Memphis, University of California San Francisco, and National Institutes of Health.

Oral Health

In both studies, objective measures of oral health were assessed through an oral examination and self-reported oral health was determined through questionnaires. Objective measures of oral health included count of remaining natural teeth and periodontal disease assessment (loss of attachment and pocket depth in participants with teeth). In the BRHS, the physical examination in 2010–2012 included a brief periodontal assessment that was conducted on 6 index teeth, 1 per sextant of the mouth.[7,20] In year 2 of the HABC Study, a full-mouth assessment of periodontal disease was performed by a dental hygienist or a periodontist.[21] Questionnaires were also administered in both studies on self-reported oral health measures, including overall self-rated oral health (excellent, good, or fair to poor); difficulty eating due to mouth, teeth, or dentures, sensitivity to hot/cold/sweets, dry mouth (Xerostomia Inventory Scale; BRHS,[22] single question; HABC). Denture use was based on self-report in the BRHS and clinical examination in the HABC. In both studies, a composite measure of the presence of any oral health problems [tooth loss; fair or poor self-rated oral health; dry mouth; sensitivity to hot, cold, or sweet (BRHS)/limit of food because of gum problems (HABC Study); and difficulty eating] was created as a more global assessment of poor oral health.

Number of natural teeth was operationalized as a continuous variable and as a 3-level categorical variable (≥21, 1–20, and 0 teeth) for use in the analyses. Dental status measure was based on ≥21 natural teeth, <21 teeth with use of dentures, and <21 teeth without use of dentures. Periodontal status measures were determined in those who were dentate and classified as 0% to 20% and >20% of sites with pocket depth >3.5 mm (BRHS) or ≥3 mm (HABC Study) pocket depth, and loss of attachment >5.5 mm (BRHS) or ≥3 mm (HABC Study). Periodontal measures cutoffs were based on assessments made in both cohorts and distribution of measures in the 2 cohorts, excluding those who were edentate; the same cutoff points have been previously used in these 2 cohort studies.[7,23] Self-rated oral health was grouped into excellent or good versus fair or poor; dry mouth

symptoms were categorized as 0, 1 to 2, and 3 or more symptoms (BRHS) or yes/no (HABC Study); difficulty eating/chewing was binary (yes or no). The composite measure of poor oral health was categorized as having 0, 1, or 2 or more oral health problems.

Physical Frailty

Physical frailty was determined based on 2 scoring tools, the Fried frailty phenotype[4] and the Gill index[14,24,25] using data from questionnaires and physical assessments. The frailty phenotype comprises 5 components: unintentional weight loss, exhaustion, weakness, low physical activity, and slowness (Supplementary Table 1). Participants with none of these components were defined as "robust"; with 1 or 2 as "pre-frail"; and with 3 or more as "frail." The Gill Index frailty criteria were based on gait speed of <0.6 m/s and the inability to stand from a chair without the use of the arms. Participants with neither criterion were defined as "robust," those with 1 criterion as "moderately frail," and those meeting both criteria as "severely frail."

Baseline Covariates

In both studies, detailed information on sociodemographic, behavioral (smoking history, alcohol intake, and diet) and health-related factors [ie, history of cardiovascular disease, diabetes, depression, prescribed medications, and plasma/serum interleukin-6 concentrations (IL-6)] were available from questionnaires and/or physical examinations at baseline. Socioeconomic position was based on occupational social class derived from the longest-held occupation when participants entered the study in the BRHS[20] and according to years of education in the HABC Study.[23] Diet quality was based on the Elderly Dietary Index and Healthy Eating Index in the BRHS and HABC Study, respectively, as previously described.[8]

Statistical Analysis

All analyses were conducted using SAS version 9.4 software (SAS Institute, Inc) and performed separately for the BRHS and HABC Study. Baseline descriptive characteristics are presented as means and SDs or as frequencies, as appropriate. Separate logistic regression models were conducted to examine the associations of each oral health marker with frailty progression based on the frailty phenotype or Gill index. Frailty status at both time points was dichotomized into 2 categories: stable/improved (reference), worsened to frail (frailty phenotype)/severely frail (Gill index). Those who were frail/severely frail at the baseline, dependent on the scoring tool, were excluded from the analysis.

Adjustments were made for baseline age as a continuous variable. Model 2 further included sociodemographic and behavioral factors: social class, alcohol consumption, smoking status, and body mass index (BMI) (kg/m^2; continuous) in the BRHS; and sex, race, education, smoking status, and BMI (kg/m^2; continuous) in the HABC Study. Only severe frailty derived from the Gill index was adjusted for physical activity (categorical), as low activity was a component of the frailty phenotype score. Model 3 was further adjusted for health factors, including history of cardiovascular disease, diabetes, depression, and IL-6 concentrations (pg/mL; continuous). Models for dry mouth and cumulative oral health problems were specifically adjusted for medications that have xerostomia as a recognized side effect. Covariates were tested for correlation before they were entered in the models.

Results

In the BRHS, 935 men (mean age 77 ± 4 years) completed both the 2010–2012 (baseline) and 2018 physical examinations and/or questionnaires (follow-up). In the HABC Study, data were available for 2033 men and women at both the year 2 (1998–1999; mean age 74 ± 3 years) (baseline) and year 10 visits (2006–2007) (follow-up). Among participants who had data available at both baseline and ~8-year follow-up, 131 (20.2%) had worsened to frailty (based on the Fried frailty phenotype) and 83 (11.2%) worsened to severe frailty (based on the Gill index) in the BRHS. In the HABC Study 85 (6.1%) worsened to frailty and 39 (2.9%) to severe frailty based on the Fried frailty phenotype and Gill index, respectively. The baseline characteristics for those who worsened to frailty, based on the frailty phenotype, and worsened to severe frailty, based on the Gill index, for both studies are presented in Table 1, and the prevalence of oral health conditions according to frailty status for both studies is presented in Supplementary Tables 2 and 3.

Oral Health and Worsening to Frailty

Odds ratios (ORs) and 95% CI for the associations between poor oral health and progression to frailty (based on frailty phenotype) in the BRHS are presented in Table 2. After full adjustment for sociodemographic, behavioral, and health-related factors, different measures of number of teeth were associated with progression to frailty: OR for number of natural teeth as a continuous variable was 0.97 (95% CI 0.95–1.00), OR for edentulism (no natural teeth vs having natural teeth) was 2.26 (95% CI 1.11–4.60), and OR for partial tooth loss (<21 teeth vs ≥ 21 teeth) was 1.79 (95% CI 1.05–3.04). Similarly, compared with those with functional dentition (≥21 teeth), those having <21 teeth with dentures (OR 1.74; 95% CI 1.02–2.96), and those having <21 teeth without dentures (OR 2.45; 95% CI 1.15–5.21) were more likely to progress to frailty. Dry mouth symptoms were also associated with frailty progression after full adjustment.

Table 3 reports ORs and 95% CI for the associations between poor oral health and progression to frailty (based on frailty phenotype) in the HABC Study. Age-adjusted associations were found for edentulism, partial tooth loss without the use of dentures, subjective difficulty eating, fair/poor self-rated oral health, dry mouth, and 2 or more cumulative oral health problems with progression to frailty. Dry mouth was associated with progression to frailty after controlling for sociodemographic and behavioural factors (OR 2.62; 95% CI 1.05–6.55); and self-reported difficulty eating (OR 2.12; 95% CI 1.28–3.50) and ≥2 cumulative oral health problems (OR 2.29; 95% CI 1.17–4.50) after further adjustment for health factors.

Oral Health and Worsening to Severe Frailty

The associations between poor oral health and progression to severe frailty based on the Gill index for the BRHS and HABC Study are presented in Tables 2 and 3, respectively. In the BRHS, age-adjusted associations were observed for number of natural teeth, dental status (natural teeth with or without dentures), difficulty eating, ≥3 dry mouth symptoms, and ≥2 cumulative oral health problems with progression to severe frailty. No associations remained significant after full adjustment. In the HABC Study, number of natural teeth, dental status and cumulative oral health problems were associated with progression to severe frailty in the age-adjusted models. After full adjustment, edentulism (OR 4.44; 95% CI 1.39–14.15) and <21 teeth without denture use (OR 3.37; 95% CI 1.17– 9.75) were associated with progression to severe frailty.

Discussion

The aim of the current study was to investigate the prospective associations between oral health and progression of physical frailty in older adults. The main finding was that there are associations between markers of poor oral health and frailty progression, as measured by the frailty phenotype in 2 cohorts of older adults from the United

Table 1
Baseline Characteristics for the Analytical Sample From the BRHS and HABC Study

	BRHS (2010–2012)			
	Fried Frailty Phenotype (n = 649)		Gill Index (n = 739)	
	Stable/improved	Worsened	Stable/improved	Worsened
n (%)	518 (79.8)	131 (20.2)	656 (88.8)	83 (11.2)
Age, y, mean ± SD	76.3 ± 3.2	79.2 ± 4.5	76.5 ± 3.5	79.5 ± 4.5
BMI (kg/m^2), mean ± SD	26.7 ± 3.4	27.5 ± 3.4	26.7 ± 3.4	28.3 ± 3.7
Manual social class, n (%)	206 (40.7)	56 (43.8)	262 (40.7)	32 (41.6)
Current smokers, n (%)	14 (2.7)	3 (2.3)	16 (2.4)	4 (4.8)
Moderate to heavy alcohol consumption, n (%)	26 (5.1)	4 (3.1)	30 (4.6)	3 (3.6)
Poor diet quality, n (%)	87 (17.8)	25 (20.5)	111 (18.0)	16 (21.6)
Self-reported severe depression or anxiety, n (%)	85 (16.8)	14 (10.9)	104 (16.2)	10 (12.2)
History of CVD, n (%)	81 (15.9)	32 (24.8)	104 (16.1)	22 (27.2)
History of diabetes, n (%)	62 (12.0)	23 (17.7)	85 (13.0)	15 (18.3)
≥2 medications with dry mouth side effect, n (%)	45 (8.7)	12 (9.2)	52 (7.9)	11 (13.3)
Plasma IL-6 (pg/mL), mean ± SD	3.30 ± 3.7	3.99 ± 3.3	3.37 ± 3.7	4.60 ± 5.1
	HABC (1998–1999)			
	Fried Frailty Phenotype (n = 1389)		Gill Index (n = 1326)	
	Stable/Improved	Worsened	Stable/Improved	Worsened
n (%)	1304 (93.9)	85 (6.1)	1326 (97.1)	39 (2.9)
Sex, n (%)				
Male	605 (46.4)	39 (45.9)	632 (47.7)	13 (33.3)
Female	699 (53.6)	46 (54.1)	694 (52.3)	26 (66.7)
Age, y, mean ± SD	74.2 ± 2.8	75.0 ± 2.8	74.2 ± 2.7	76.2 ± 2.8
BMI (kg/m^2), mean ± SD	27.2 ± 4.5	28.4 ± 5.6	27.1 ± 4.5	28.4 ± 5.4
Race, n (%)				
White	894 (68.6)	50 (58.8)	903 (68.1)	16 (41.0)
African American	410 (31.4)	35 (41.2)	423 (31.9)	23 (59.0)
Education, n (%)				
Less than high school	235 (18.0)	23 (27.1)	243 (18.4)	15 (38.5)
High school graduate	411 (31.5)	30 (35.3)	417 (31.5)	10 (25.6)
Post-secondary	657 (50.4)	32 (37.7)	664 (50.2)	14 (35.9)
Current smokers, n (%)	85 (6.5)	6 (7.1)	83 (6.3)	4 (10.3)
Poor diet quality, n (%)	88 (6.8)	6 (7.1)	85 (6.4)	3 (7.7)
History of depression, n (%)	45 (3.5)	9 (10.6)	49 (3.7)	1 (2.6)
History of CVD, n (%)	277 (21.2)	27 (31.8)	283 (21.3)	12 (30.8)
History of diabetes, n (%)	202 (15.5)	20 (23.5)	207 (15.6)	12 (30.8)
≥1 medications with dry mouth side effect, n (%)	736 (56.5)	59 (69.4)	759 (57.3)	30 (76.9)
Plasma IL-6 (pg/mL), mean ± SD	3.09 ± 3.4	3.27 ± 2.1	3.02 ± 3.3	4.10 ± 5.1

Data are mean ± SD unless otherwise stated.
CVD, cardiovascular disease.

Kingdom and the United States, that persisted even after controlling for sociodemographic and behavioral factors, comorbidities, and IL-6 concentration (a biomarker of systemic inflammation). In contrast, the associations between poor oral health and progression to severe frailty (Gill index) were mostly attenuated in the adjusted models, apart from edentulism and <21 teeth without the use of dentures which remained significant in the HABC Study only. The findings of the current study add to a growing body of evidence that indicate that maintenance of oral health may be important in preventing frailty progression in older adults.[6]

In the BRHS, compared with those with functional dentition, fewer remaining natural teeth with or without denture use was associated with frailty progression. In addition, each additional natural tooth retained was associated with a reduced risk of frailty, in agreement with a previous study.[26] In the HABC Study those with <21 teeth and no dentures had higher odds of progressing to severe frailty, but not those who wore dentures. The differences in the causes underlying tooth loss and/or in management of tooth loss and quality of dental prothesis used in the UK and USA study populations might also be responsible for these observed differences in the two studies. Tooth loss has been shown to affect masticatory function, nutritional choices, and diet quality that might increase risk of adverse outcomes, such as frailty.[8,27] In the current study, self-reported difficulty eating was associated with progression to severe frailty in the BRHS and to frailty in the HABC Study, but these associations did not remain significant after full adjustment in the BRHS. It is important to acknowledge that the current study did not take in to account the severity of difficulty eating and therefore this might not have been the most reliable measure of detecting changes in nutritional intake. In a previous study, frailty was only associated with higher level of difficulty eating a number of foods.[28] The difficulty eating pathway has been supported by a previous study, in that non–denture users with <20 teeth had higher odds for low grip strength, a component of frailty, and nutritional intake indirectly explained approximately a third of this relationship.[29] Although the results from the BRHS, in line with others,[30] suggest that use of dentures might not completely attenuate this relationship, it may mean that dentures do not fully restore oral function. Denture types (for example, full or partial) represent different challenges for restoration and functionality in older people and should be investigated in future studies.

In both cohorts, self-reported dry mouth was associated with progression to frailty, despite different methods of assessment. Dry mouth is often a consequence of medication for chronic age-related diseases,[31] adversely affecting taste, appetite and nutrition intake, and also causing ulceration, dental diseases, and systemic inflammation that might be related to frailty.[32–35] However, it should be acknowledged that dry mouth and frailty may have occurred

Table 2
OR (95% CI) for Progression to Frailty or Severe Frailty Versus Stable/Improved According to Baseline Oral Health in the BRHS

Oral Health at Baseline (2010–2012)	Worsened to Frailty (Fried Frailty Phenotype)			Worsened to Severe Frailty (Gill Index)		
	Age-Adjusted	Model 2	Model 3	Age-Adjusted	Model 2*	Model 3
Number of natural teeth						
≥ 21	1.00 (ref)			1.00 (ref)		
1–20	**1.97 (1.25–3.13)**	**1.87 (1.13–3.08)**	**1.79 (1.05–3.04)**	**1.83 (1.04–3.21)**	1.56 (0.81–2.98)	1.44 (0.73–2.85)
0	**1.99 (1.06–3.71)**	**2.08 (1.06–4.11)**	**2.26 (1.11–4.60)**	**2.74 (1.24–4.92)**	1.82 (0.83–4.01)	1.50 (0.63–3.62)
As continuous (per additional tooth)	**0.97 (0.95–0.99)**	**0.97 (0.95–1.00)**	**0.97 (0.95–1.00)**	**0.96 (0.94–0.99)**	**0.97 (0.95–1.00)**	0.98 (0.95–1.01)
Dental status						
≥21 teeth	1.00 (ref)			1.00 (ref)		
<21 teeth with dentures	**1.77 (1.12–2.80)**	**1.77 (1.07–2.91)**		**1.96 (1.14–3.40)**	1.63 (0.87–3.07)	1.38 (0.70–2.71)
<21 teeth no dentures	**2.78 (1.44–5.37)**	**2.52 (1.23–5.17)**		**1.93 (0.85–4.38)**	1.61 (0.63–4.12)	1.73 (0.66–4.54)
Pocket depth (Percentage of sites >3.5 mm)						
0%–20%	1.00 (ref)			1.00 (ref)		
>20%	1.27 (0.76–2.14)	1.14 (0.65–2.00)	1.10 (0.60–2.00)	1.09 (0.59–2.01)	1.10 (0.54–2.26)	0.93 (0.42–2.06)
Loss of attachment (Percentage of sites >5.5 mm)						
0%–20%	1.00 (ref)			1.00 (ref)		
>20%	1.41 (0.81–2.44)	1.28 (0.71–2.31)	1.29 (0.68–2.44)	0.97 (0.49–1.91)	1.03 (0.48–2.22)	1.11 (0.48–2.53)
Difficulty eating						
No	1.00 (ref)			1.00 (ref)		
Yes	1.28 (0.60–2.69)	1.32 (0.61–2.88)	1.16 (0.50–2.71)	**2.50 (1.22–5.14)**	2.10 (0.88–5.02)	2.10 (0.81–5.49)
Subjective oral health						
Good/excellent	1.00 (ref)					
Fair/poor	1.41 (0.92–2.16)	1.43 (0.89–2.29)	1.26 (0.77–2.07)	1.25 (0.76–2.07)	1.25 (0.70–2.26)	1.26 (0.67–2.37)
Dry mouth symptoms†						
0	1.00 (ref)			1.00 (ref)		
1–2	**2.22 (1.23–3.99)**	**2.30 (1.23–4.33)**	**2.43 (1.25–4.71)**	1.68 (0.83–3.43)	1.73 (0.76–3.93)	1.54 (0.64–3.69)
≥3	**1.92 (1.20–3.09)**	**1.78 (1.08–2.95)**	**1.81 (1.06–3.10)**	**2.02 (1.16–3.51)**	1.82 (0.96–3.43)	1.68 (0.86–3.29)
Cumulative oral health problems†,‡						
0	1.00 (ref)			1.00 (ref)		
1	1.20 (0.71–2.04)	1.21 (0.69–2.15)	1.27 (0.69–2.32)	1.61 (0.80–3.24)	1.56 (0.68–3.58)	1.30 (0.55–3.04)
≥2	1.53 (0.88–2.68)	1.49 (0.81–2.75)	1.38 (0.72–2.65)	**2.81 (1.40–5.67)**	**2.58 (1.12–5.94)**	2.30 (0.98–5.41)

Model 2 also adjusted for social class, smoking, alcohol, diet quality, BMI.
Model 3 further adjusted for history of cardiovascular disease and diabetes and self-reported depression and anxiety and IL-6.
Adjustments also included *physical activity 3 levels (moderate-vigorous, occasional/light and inactive) and †medications with xerostomia as side effect ‡<21 teeth, ≥3 dry mouth symptoms, difficulty eating, sensitivity to hot/cold/sweets.
Bold indicates significance $P < .05$.

Table 3
OR (95% CI) for Progression to Frailty or Severe Frailty Versus Stable/Improved According to Baseline Oral Health in the HABC Study

Oral Health at Baseline (1998–1999)	Worsened to Frailty (Fried Frailty Phenotype)			Worsened to Severe Frailty (Gill Index)		
	Age-Adjusted	Model 2	Model 3	Age-Adjusted	Model 2*	Model 3
Number of natural teeth						
≥ 21	1.00 (ref)			1.00 (ref)		
1–20	1.61 (0.87–2.98)	1.37 (0.71–2.65)	1.25 (0.63–2.45)	**2.71 (1.13–6.47)**	2.04 (0.83–5.05)	1.59 (0.63–4.00)
0	**3.08 (1.31–7.29)**	2.33 (0.89–6.11)	2.03 (0.73–5.63)	**8.01 (2.88–22.27)**	**5.97 (1.95–18.28)**	**4.44 (1.39–14.15)**
As continuous (per additional tooth)	**0.97 (0.94–1.00)**	0.98 (0.95–1.02)	0.99 (0.96–1.03)	**0.94 (0.90– 0.97)**	**0.95 (0.91–0.99)**	0.96 (0.92–1.00)
Dental status						
≥ 21 teeth	1.00 (ref)			1.00 (ref)		
< 21 teeth with dentures	1.80 (0.97–3.36)	1.48 (0.75–2.89)	1.33 (0.66–2.66)	**2.89 (1.20–7.01)**	2.06 (0.82–5.16)	1.53 (0.59–3.96)
< 21 teeth no dentures	1.92 (0.85–4.34)	1.56 (0.65–3.73)	1.39 (0.56–3.44)	**5.28 (1.97–14.13)**	**4.17 (1.48–11.77)**	**3.37 (1.17–9.75)**
Pocket depth (Percentage of sites >3 mm)						
0%–20%	1.00 (ref)			1.00 (ref)		
>20	1.31 (0.59–2.91)	1.29 (0.55–3.02)	1.26 (0.53–2.99)	4.70 (0.99–22.20)	3.70 (0.70–19.53)	3.29 (0.61–17.69)
Loss of attachment (Percentage of sites >3 mm)						
%–20%	1.00 (ref)			1.00 (ref)		
>20%	0.95 (0.43– 2.15)	0.92 (0.38–2.20)	1.03 (0.42–2.52)	2.46 (0.52–11.62)	2.48 (0.47–13.01)	3.43 (0.52–22.56)
Difficulty eating						
No	1.00 (ref)			1.00 (ref)		
Yes	**2.49 (1.55–4.02)**	**2.26 (1.39–3.68)**	**2.12 (1.28–3.50)**	1.42 (0.66–3.06)	1.17 (0.53–2.57)	0.87 (0.37–2.07)
Subjective oral health						
Good/excellent	1.00 (ref)			1.00 (ref)		
Fair/poor	**1.84 (1.17–2.90)**	1.59 (0.99–2.57)	1.54 (0.94–2.52)	1.78 (0.91–3.47)	1.06 (0.51–2.21)	0.97 (0.45–2.08)
Dry mouth symptoms†						
No	1.00 (ref)			1.00 (ref)		
Yes	**2.80 (1.14–6.88)**	**2.62 (1.05–6.55)**	2.45 (0.96–6.23)	3.08 (0.89–10.65)	2.92 (0.81–10.59)	2.81 (0.77–10.27)
Cumulative oral health problems†,‡						
0	1.00 (ref)			1.00 (ref)		
1	1.76 (0.97–3.20)	1.56 (0.84–2.88)	1.41 (0.75–2.63)	**4.06 (1.53–10.75)**	**2.98 (1.10–8.11)**	2.68 (0.98–7.30)
≥2	**3.32 (1.77–6.23)**	**2.83 (1.47–5.47)**	**2.29 (1.17–4.50)**	**3.26 (1.07–9.89)**	2.13 (0.68–6.72)	1.39 (0.42–4.62)

Model 2 also adjusted for education level, smoking, diet quality, BMI.
Model 3 further adjusted for history of cardiovascular disease, diabetes, depression and baseline IL-6 levels.
Adjustments also included *physical activity 2 levels (lowest quintile vs top 4 quintiles) and †medications with xerostomia as side effect.
‡<21 teeth, dry mouth when eating, difficulty eating or chewing and limiting food because of gum problems.
Bold indicates significance $P < .05$.

simultaneously as a result of other age-related comorbidities, medications, and psychological factors, making the relationship complex. The associations in the BRHS remained significant even after controlling for medications with xerostomia (dry mouth) as a recognized side effect, chronic diseases, diet, and IL-6, adding confidence to these findings. The association with dry mouth remained significant in the HABC Study also after controlling for sociodemographic and behavioural factors, but was attenuated on adjustment for health factors and IL-6, demonstrating these complexities. In addition to the adverse consequences of poor nutritional status, inflammation represents another potential underlying pathway that might mediate the relationship between poor oral health and risk of frailty by affecting organs and tissues distant to the oral cavity and decreasing functional reserve capacities.[26,36] Low-grade chronic inflammation can exacerbate muscle wasting, by stimulating muscle catabolism and suppressing protein synthesis leading to reduced physical function and frailty.[35,37,38] Nevertheless, these data are in line with previous studies and highlight the potential role of dry mouth as an indicator of frailty in later life.[7,39] In addition, we confirmed previous associations[7] that composite or cumulative oral health problems, including dry mouth, were associated with frailty progression in the HABC Study. Consistent with this, in a recent study in older Canadian adults, number of oral health problems was associated with the frailty index, suggesting worsening of frailty with each additional adverse oral health factor.[40]

Although the link between periodontal disease and frailty has been reported,[26] this was not observed in the current study. A smaller sample (only those with natural teeth) for this analysis may have led to lack of power to detect an association between periodontal status and progression of frailty. Furthermore, the limited associations between severe frailty (Gill index) and oral health might be as a result of the frailty phenotype comprising of more domains (including lower and upper body physical performance, weight loss, exhaustion, and physical activity) increasing the likelihood that the phenotype will detect frailty,[41] and thus increase the power to establish associations. It has been well documented that poor oral health can negatively affect nutritional intake,[42] and has shown to be a strong predictor of weight loss, a component of the frailty phenotype.[43] In another study, people with missing teeth were more likely to have impaired mastication, which was associated with fatigue, low physical activity, slow gait speed, and overall frailty.[11] Therefore, oral health might differentially affect other frailty-related domains rather just than lower body physical performance (the focus of the Gill index). Moreover, there was a lower proportion of those who worsened to severe frailty at follow-up according to the Gill index in both studies, and to either frailty score in the HABC Study, factors that may help explain the different associations observed between the 2 scores and studies.

This study has several strengths, including the relatively large samples of 2 cohorts of community-dwelling older adults with detailed information on oral health, use of 2 measures of physical frailty, and follow-up for a long period (~8 years). In addition, we included several important covariates in the models, including markers of diet quality and inflammation that had not previously been included in previous studies of this nature. Nonetheless, we cannot exclude the possibility of residual confounding, which needs careful consideration. In addition, the generalizability of findings could be limited due to studies comprising White men (BRHS) and White and African American men and women from only 2 areas in the United States (HABC Study). Moreover, because both frailty and oral health status are dynamic, not static, processes, the temporal and bidirectional relationship should be the focus of future longitudinal studies to help strengthen evidence for potential causal links between oral health and frailty. Furthermore, the frailty measures we have used did not take account of cognitive decline or psychosocial aspects.

Conclusions and Implications

In conclusion, we add to previous findings that objective markers of oral health, such as number of natural teeth and the presence of periodontitis, are prospectively associated with progression of physical frailty. In addition, within 2 different cohorts of older adults, we identified that self-reported dry mouth is independently associated with frailty progression in older adults. These data once again highlight that simple markers of poor oral health (that can easily be ascertained in clinical and long-term care settings) could facilitate early detection of the risk of physical frailty in older adults.

Author Contributions

Study concept and design: RK, SER, SGW, AOP, PHW, JCM, and LTL. Acquisition of data: SER, SGW, AOP, PHW, and LTL. Analysis and interpretation of data: All authors. Drafting of the manuscript: All authors. Critical revision of the manuscript for important intellectual content: All authors.

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Appendix

Supplementary Table 1
Operationalization of Frailty According to the Frailty Phenotype of Fried et al[4,7,44]

Criterion (Yes/No)	BRHS		HABC Study	
	Response Item/Functional Measure	Notes*	Response Item/Functional Measure	Notes*
Unintentional weight loss	≥5% self-reported weight loss from previous questionnaire (2007).	Specified not trying to lose weight or no change/ unknown change in weight but a substantial measured weight loss (ie, ≥5%) since the previous assessment. If missing and self-reported weight loss of more than 7 pounds (3 kg) in past 3 months, then coded as unintentional weight loss.	≥5% self-reported weight loss from previous annual body weight measurements at the examination (year 1; 1997 −1998).	Specified not trying to lose weight or no change/ unknown change in weight but a substantial measured weight loss (ie, ≥5%) since the previous assessment coded as unintentional weight loss.
Fatigue	"Do you feel full of energy?"	Answering "no" coded as fatigue.	"In the past month, on the average, have you been feeling unusually tired during the day?" and "Please describe your usual energy level in the past month, where 0 is no energy and 10 isthe most energy that you have ever had"	Answering "yes" and "all of the time" or "most of the time" or ≤ 3 coded as fatigue.
Low physical activity	"Compared with a man who spends 2 hours on most days on activities such as: walking, gardening, household chores, DIY projects, how physically active would you consider yourself?"	Answering "much less active" coded as low physical activity. If missing information on self-reported walking, cycling and sporting physical exercise used to determine activity level.	kcal/wk spent on commonly performed physical activities: walking, climbing stairs, and doing major chores calculated from a modified leisure-time physical activity questionnaire.	Lowest quintile stratified by sex coded as low physical activity.
Weakness	Grip strength (Jamar Hydraulic Hand Dynamometer Model J00105) highest of 3 readings in both hands.	Lowest quintile coded as weak. Where measured grip strength was unavailable self-reported weak grip strength or inability to grip with hands (eg, opening a jam jar) was coded as weakness.	Grip strength (Jamar isometric dynamometer JLW Instruments, Chicago) highest of 2 readings in both hands.	Lowest quintile stratified by sex coded as weak. Where measured grip strength was unavailable due to pain or surgery on both hands or self-reported inability or a lot of difficulty to grip with hands using your fingers to grasp or handle was coded as weak.
Slow walking speed	Gait speed (m/s) based on the time required to walk 3 m at normal pace.	Lowest quintile coded as slow walking speed. Where measured gait speed was unavailable, self-report of low walking pace (or being unable to walk more than a few steps, or <200 yards (approximately 180 m), or difficulty walking across a room) was used to determine slowness.	Gait speed (m/s) based on the time required to walk 20 m at usual pace.	Lowest quintile stratified by sex coded as slow walking speed. Where measured gait speed was unavailable, self-report of great difficulty or inability to walk 0.25 mile was used to determine slowness.

*Those with 3 or more criteria missing excluded.

Supplementary Table 2
Prevalence of Oral Health Conditions Based on Frailty Status in the BRHS

	Fried Frailty (n = 649)				Gill Index (n = 739)			
	Stable/Improved		Worsened		Stable/Improved		Worsened	
	n	%	n	%	n	%	n	%
Number of natural teeth								
≥21	247	48	39	30	294	45	22	27
1–20	189	36	66	50	250	38	40	48
0	62	12	23	18	84	13	19	23
missing	20	4	3	2	28	4	2	2
Dental status								
≥21 teeth	243	47	39	30	288	44	22	27
<21 teeth with dentures	204	39	66	50	270	41	48	58
<21 teeth no dentures	43	8	21	16	60	9	10	12
missing	28	5	5	4	38	6	3	4
Pocket depth (Percentage of sites >3.5 mm)								
0%–20%	322	62	29	22	404	62	45	54
>20%	103	20	70	53	139	21	17	20
missing	93	18	32	24	113	17	21	25
Loss of attachment (Percentage of sites >5.5 mm)								
0%–20%	351	68	74	56	444	68	49	59
>20%	74	14	25	19	99	15	30	36
missing	93	18	32	24	113	17	21	25
Difficulty eating								
No	341	66	85	65	423	64	52	63
Yes	33	6	12	9	39	6	13	16
missing	144	28	34	26	194	30	18	22
Subjective oral health								
Good/excellent	361	70	77	59	447	68	50	60
Fair/poor	146	28	49	37	191	29	30	36
missing	11	2	5	4	18	3	3	4
Dry mouth symptoms								
0	223	43	40	31	269	41	25	30
1–2	88	17	28	21	116	18	15	18
≥3	199	38	59	45	251	38	41	49
missing	8	2	4	3	20	3	2	2
Cumulative oral health problems*								
0	133	26	27	21	172	26	12	14
1	246	47	58	44	305	46	34	41
≥2	139	27	46	35	179	27	37	45

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

Supplementary Table 3
Prevalence of Oral Health Conditions Based on Frailty Status in the HABC Study

	Fried Frailty (n = 1389)				Gill Index (n = 1326)			
	Stable/Improved		Worsened		Stable/Improved		Worsened	
	n	%	n	%	n	%	n	%
Number of natural teeth								
≥21	517	40	20	24	537	41	8	21
1–20	369	28	23	27	376	46	15	39
0	69	5	8	9	70	5	8	21
missing	349	27	34	40	343	26	8	21
Dental status								
≥21 teeth	517	40	20	24	537	41	8	21
<21 teeth with dentures	313	24	22	26	314	24	14	36
<21 teeth no dentures	125	10	9	11	132	10	9	23
missing	349	27	34	40	343	26	8	21
Pocket depth (Percentage of sites >3.5 mm)								
0%–20%	289	22	11	13	295	22	2	5
>20%	307	24	15	18	324	24	9	23
missing	708	54	59	63	707	53	28	72
Loss of attachment (Percentage of sites >5.5 mm)								
0%–20%	227	17	10	12	244	18	2	5
>20%	368	28	16	19	374	28	9	23
missing	709	54	59	69	708	53	28	72
Difficulty eating								
No	1085	83	57	67	1087	82	30	77
Yes	217	17	28	33	237	18	9	23
missing	2	0	0	0	2	0	0	0
Subjective oral health								
Good/excellent	963	74	52	61	964	73	23	59
Fair/poor	335	26	33	39	355	27	15	39
missing	6	1	0	0	7	1	1	3
Dry mouth symptoms								
No	1261	97	78	92	1279	42	36	92
Yes	37	3	6	7	40	3	3	8
missing	6	1	1	0	7	1	0	0
Cumulative oral health problems*								
0	433	33	16	19	446	34	5	13
1	622	48	39	46	618	47	25	64
≥2	249	19	30	35	262	20	9	23
missing	0	0	0	0	0	0	0	0

*<21 teeth, dry mouth when eating, difficulty eating or chewing and limiting food because of gum problems.