Journal of Dental Research
2020, Vol. 99(9) 1047–1053

DOI: 10.1177/0022034520916151
journals.sagepub.com/home/jdr

Flossing Is Associated with Improved Oral Health in Older Adults

J.T. Marchesan[1], K.M. Byrd[2], K. Moss[2], J.S. Preisser[3], T. Morelli[1], A.F. Zandona[4], Y. Jiao[1], and J. Beck[1]

Abstract

The effect of preventive oral habits is largely unexplored in older individuals. The purpose of this study was to evaluate the associations between home use of flossing and prevalence of periodontal disease and caries in older adults. Five-year incident tooth loss was also evaluated. Data on 686 individuals ≥65 y-old from the Piedmont 65+ Dental Study were examined including: 1) interproximal clinical attachment level (iCAL), 2) interproximal probing depth (iPD), 3) numbers of caries, and 4) missing teeth. Flossing behavior was evaluated according to the Periodontal Profile Class (PPC) system. Five-year follow-up data (n = 375) was evaluated for incident tooth loss. Dichotomous and categorical variables were analyzed using Pearson chi-square tests as well as covariate-adjusted Cochran-Mantel-Haenszel tests. Multiple linear regression compared clinical parameters based on flossing behavior. Elderly flossers had lower (mean, SE) %iCAL≥3 mm (38.2, 2.38 vs. 48.8, 1.56) and %iPD≥4 mm (8.70, 1.41 vs. 14.4, 0.93) compared to nonflossers ($P \leq 0.005$). Flossers showed less coronal caries compared to nonflossers ($P = 0.02$). Baseline number of missing teeth (mean, SE) was 11.5 (0.35) in nonflossers compared to 8.6 (0.53) in flossers ($P < 0.0001$). Regular dental visitors had lower oral disease levels compared to episodic dental users. The majority of flossers classified into PPC-Stage I (health) whereas nonflossers classified as PPC-Stages V, VI, and VII (disease). At the 5-y follow-up visit, the average tooth loss for flossers was ~1 tooth compared to ~4 teeth lost for nonflossers ($P < 0.0001$). Among all teeth, molars showed the highest benefit (>40%) for flossing behavior ($P = 0.0005$). In conclusion, the extent of oral disease for older individuals was significantly less in flossers than in nonflossers. Flossers showed less periodontal disease, fewer dental caries, and loss of fewer teeth over a 5-y period. These findings further support flossing as an important oral hygiene behavior to prevent oral disease progression in older adults.

Keywords: OHI, interdental cleaning, elderly, prevention, periodontal disease, caries

Introduction

With the world population aging, there is a growing focus on what constitutes health in older adult populations (World Health Organization 2015). Good oral health is considered a key factor in healthy ageing and is associated with improved general health, reduced morbidity and mortality in older adults (Holm-Pedersen et al. 2008; Tonetti et al. 2017). Since there is a consistent peak of severe tooth loss at the age of 65 over the past 2 decades, it is important to understand whether preventive oral hygiene regimens in older adults can improve oral health and tooth retention (Tonetti et al. 2017).

The key to promoting optimal oral health in older adults is to control its two most common diseases—periodontal disease and caries—which are chronic multifactorial diseases of which microbial biofilm are a fundamental etiology (Loe et al. 1965; Beck and Drake 1975; Listgarten et al. 1975; Hunt et al. 1992; Guggenheim et al. 2004; Socransky and Haffajee 2005; Curtis et al. 2011; Hajishengallis et al. 2012; Jiao et al. 2013; Teles et al. 2013; Takahashi 2015; Sanz et al. 2017). A change in the microbial communities (dysbiosis) of the tooth-adherent dental plaque is consistently related to the progression from oral health to disease (Feres et al. 2016; Sanz et al. 2017). Therefore, the mechanical disruption of microbial biofilm's adherence to the tooth by toothbrushing and interdental cleaning is recommended as part of home care (Jepsen et al. 2017).

There is a need for epidemiological surveillance of oral disease and tooth loss in older populations (Tonetti et al. 2017). We and others have previously addressed the challenges of conducting randomized clinical trials to evaluate prevention of oral disease by flossing/interdental cleaning, which include a)

[1]Department of Comprehensive Oral Health, Adams School of Dentistry, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[2]Department of Oral and Craniofacial Health Sciences, Adams School of Dentistry, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[3]Department of Biostatistics, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[4]Department of Comprehensive Care, School of Dental Medicine, Tufts University, Boston, MA, USA

A supplemental appendix to this article is available online.

Corresponding Author:
J.T. Marchesan, Department of Comprehensive Oral Health, Periodontology, Adams School of Dentistry, University of North Carolina at Chapel Hill, 3506 Koury Oral Health Sciences Building, Campus Box #7455, Chapel Hill, NC 27599-7455, USA.
Email: julie_marchesan@unc.edu

ethical reasons of assigning individuals into a nonflossing regimen, b) amount of time required for the development of caries and periodontal disease, and c) funding issues to support this type of study (Vernon et al. 2017; Vernon and Seacat 2017; Marchesan et al. 2018). Randomized controlled trials (RCTs) are often expensive and some fail to generate useful evidence for clinical practices (Mc Cord et al. 2018). Other types of studies that are used to measure the effectiveness of an intervention include observational studies that represent nonexperimental "real world" scenarios at the population level (Anglemyer et al. 2014). Previous evaluations by our group of available cross-sectional data from the National Health and Nutrition Examination Survey (NHANES 2011–2012 and 2013–2014) showed that interdental cleaning was associated with less oral disease, including caries, periodontal disease parameters, and number of teeth (Marchesan et al. 2018). While this study evaluated a large number of individuals (n = 6,891), it did not provide longitudinal information. In addition, the NHANES study surveys adults aged over 30 y of age, with a mean age of ~50 y of age (Marchesan et al. 2018) and does not directly address older individuals who live in the community. In children, professional flossing done for 1.7 y reduced the risk for developing caries by 40% (Hujoel et al. 2006), and recent analysis of multiple RCTs showed that the usage of floss—in addition to toothbrushing—in adults may reduce gingivitis or plaque compared to brushing alone at 1, 3, and 6 mo (Worthington et al. 2019). This emerging evidence further supports flossing as an effective intervention for reducing the burden of oral disease.

The purpose of this study was to evaluate the associations between home use of flossing and prevalence of periodontal disease and caries in older adults. Five-year incident tooth loss was also evaluated. We hypothesized that elderly individuals who flossed had improved oral health and lost less teeth over a 5-y period when compared to nonflossers. In this present study, we accessed longitudinal data available from the Piedmont 65+ Dental Study (Dental PDS) that collected data from individuals aged ≥65 y over a 5-y period. We evaluated if flossing, in addition to tooth brushing, was associated with a) less periodontal disease, b) fewer coronal and interproximal caries, and c) fewer teeth lost over a 5-y period when compared to brushing alone.

Methods

The Piedmont Health Study of the Elderly is the parent study of the Piedmont 65+ Dental Study (Dental PDS) and was a cohort of the health status of a random sample of noninstitutionalized people aged ≥65 in five contiguous North Carolina counties (Brown et al. 1994; Beck et al. 1997). In 1988 the University of North Carolina initiated Dental PDS from the parent population, which selected a random sub-sample stratified on dentate status and race. The study conforms to STROBE guidelines. Dental examinations and interviews were conducted in the home (private residence) of the participants by one of five calibrated examination teams composed of a dentist-examiner and a recorder. Dental examinations were conducted at baseline (1988) and at 5 y (1993) using the same methodology. Detailed descriptions of the study sampling methods are published elsewhere (Graves et al. 1992; Drake et al. 1994). Clinical measurements (probing depth and clinical attachment level) were evaluated at the mesial-buccal and buccal region of all present teeth (up to 32 teeth). A total of 686 individuals were evaluated based on the available clinical data: percent of sites with interproximal clinical attachment levels (iCAL)≥3 mm, percent of sites with interproximal probing depth (iPD)≥4 mm, number of coronal and interproximal caries (unfilled), number and type of lost teeth in a 5-y period. A PD≥4 mm and a CAL≥3 mm were selected based on previous studies using these as variables for periodontal pathologic features, including our previous study that evaluated the interdental cleaning behavior of NHANES participants (Moss et al. 2009; Akinkugbe et al. 2017; Marchesan et al. 2018).

To evaluate the influence of the behavior on current periodontal disease classification systems, we used the PPC-Stages classification developed at the University of North Carolina at Chapel Hill (Morelli et al. 2017; Beck et al. 2018; Morelli et al. 2018). The PPC-Stages classification is based on number of teeth, crowns, probing depth, clinical attachment level, bleeding on probing, plaque index, and gingival index that are imputed into an algorithm and classify individuals into 7 categories [from PPC-Stage I (Health) to Stage VII (Severe tooth loss)] (Morelli et al. 2017; 2018). Information for decayed, interproximally decayed, and missing teeth was evaluated for 686 individuals. Longitudinal information on the number of teeth at 60-mo (5-y) was utilized for the tooth loss analysis (n = 375).

Flossing exposure was assessed based on the question: "Do you use dental floss? How often?". The following answers were given as options: Answer: "A) Not at all, B) Daily (7 times per week), C) Several times per week (2 to 6 times), D) One time per week, E) Less often than once per week". Individuals were divided into 2 main categories of nonflossers (response A) Not at all) and flossers (responses B–E).

Dental utilization (dental treatment) was assessed based on the following question: "Would you say that you use a dentist on a regular basis, or do you only go when you are in discomfort or when you need something fixed?". The answers given as options were: "A) Regular basis, B) Only when in discomfort, C) When something needs to be fixed, D) Don't go to the dentist". Individuals were divided into 2 categories of regular users (response A) Regular basis) and episodic (responses B–D).

Statistical Analysis

Pearson chi-square tests were used to compare demographic variables between flossers and nonflossers. Multiple linear regression adjusted for race, sex, age, diabetes, smoking, education, brushing, and dental utilization was used to compare clinical parameters based on flossing behavior. Sensitivity

Table 1. Demographics According to Flossing Behavior (n = 686).

	Nonflossers	Flossers	*P* Value
Age, y, mean (SD)	73.6 (5.9)	72.3 (5.0)	0.002
African American	315 (68.2)	64 (28.6)	<0.0001
Caucasian	147 (31.8)	160 (71.4)	
Female	247 (53.5)	153 (68.3)	0.0002
Male	215 (46.5)	71 (31.7)	
Diabetics	92 (20.0)	27 (12.1)	0.01
Nondiabetic	369 (80.0)	197 (88.0)	
Smoker	93 (20.1)	41 (18.3)	0.57
Nonsmoker	369 (79.9)	183 (81.7)	
Basic Education	395 (85.9)	109 (48.7)	
Intermediate Education	29 (6.3)	44 (19.6)	<0.0001
Advanced Education	36 (7.8)	71 (31.7)	
Episodic dental utilization	362 (80.8)	49 (21.9)	<0.0001
Regular dental utilization	86 (19.2)	175 (78.1)	

Data are presented as n (%) unless otherwise indicated.

analysis was done to account for individuals who were lost to follow-up at the 5-y visit. Five-year tooth loss models were weighted using the inverse of the predicted probability of being followed versus dropout using study demographics.

Results

Demographics and Clinical Characterization

The baseline demographics of the individuals included in the study varied by flossing behavior (Table 1). Mean age was slightly higher in nonflossers than flossers (73.6 vs. 72.3, P = 0.002). Compared to flossers, a higher percentage of nonflossers were African Americans, males, diabetic, had a basic education and infrequent dental visits. Conversely when compared to nonflossers, a higher percentage of flossers were Caucasians, females, non diabetic, with advanced education, and regular dental visits when compared to nonflossers (Table 1). Nonflossers had a greater tendency to be smokers than flossers, but the difference was not statistically significant (P = 0.57).

For the analysis at 5 y, 311 (45.3%) individuals were lost to follow-up. Younger individuals, females, and those with regular dental utilization were statistically significantly more likely to have completed the 5-y follow-up (Appendix Table 1). The most frequent reason that individuals did not complete the 5-y follow-up visit was death (n = 121, 38.9%; Appendix Table 2).

Flossing and Oral Disease

Our analysis shows that individuals identified as flossers demonstrated a statistically significant lower number of sites with interproximal clinical parameters of periodontal disease (iCAL≥3 mm, iPD≥4 mm; Table 2). In addition, individuals who flossed also had less coronal caries (P = 0.02) and a trend for fewer interproximal caries (P = 0.06, Table 2). Individuals who flossed also showed significantly lower numbers of missing teeth even when third molars were excluded (P < 0.0001).

Table 2. Clinical Parameters (mean, SE) of Periodontal Disease, Caries, and Number of Missing Teeth Stratified by Flossing Behavior (n = 686).

	Nonflossers	Flossers	*P* Value
iCAL≥3 mm (% sites)	48.8 (1.56)	38.2 (2.38)	0.0008
iPD≥4 mm (% sites)	14.4 (0.93)	8.70 (1.41)	0.002
Coronal caries (surfaces)	1.16 (0.10)	0.66 (0.16)	0.02
Interproximal caries (surfaces)	0.56 (0.06)	0.35 (0.08)	0.06
Missing teeth (n)	14.7 (0.38)	11.8 (0.58)	0.0001
Missing teeth (n excluding third molars)	11.5 (0.35)	8.6 (0.53)	<0.0001

Means adjusted for race, sex, age, diabetes, smoking, education, brushing, and dental utilization; *P* values based on multiple linear regression.
iCAL, interproximal clinical attachment level; iPD, interproximal probing depth.

Mean number of missing teeth excluding third molars in nonflossers was 11.5 (0.35) compared to 8.6 (0.53) in flossers (Table 2).

Table 3 stratifies the relationships from Table 2 by regular and episodic dental use. In general, episodic dental users have higher levels of disease than regular dental users. Table 3 indicates that periodontal parameters of iCAL and iPD were significantly lower only for flossers compared to nonflossers that were regular dental users, with a similar trend that did not reach statistical significance observed for episodic dental users. On the other hand, flossers who were episodic dental users had significantly fewer coronal carious lesions with a non significant similar trend for regular dental users. Interproximal caries surfaces did not show significant differences between flossers and nonflossers, but a strong trend favoring flossers was seen in episodic dental users (Table 3, P = 0.06). Flossing behavior favored numbered of teeth regardless of the dental utilization, with flossers having an additional ~2 teeth if they were episodic dental users and ~3.5 teeth if they were regular dental users (Table 3).

We then evaluated the distribution of individuals based on different periodontal disease classification systems and stratified these classes by flossing behavior. When comparing flossing behavior categories using the PPC-Stages classification system, flossers were more likely to be PPC-Stage I Health (Table 4). Nonflossers were more likely to be Stage V, VI, and VII of disease (Table 4).

Flossing and 5-y Tooth Loss

We evaluated the number of individuals that had lost teeth for each oral hygiene regimen group (flossers and nonflossers) during the 5-y period. The majority of individuals (regardless of their flossing habit) retained their teeth rather than losing one or more tooth, with a range of 58.6% to 91.9% individuals retaining their teeth between both flossing categories (Table 5). Overall, the percent of individuals retaining their teeth was significantly higher among flossers. This pattern was true when evaluating individuals retaining all incisors, canines, and

Table 3. Clinical Parameters (mean, SE) of Periodontal Disease, Caries, and Number of Missing Teeth Stratified by Dental Visits and Flossing Behavior ($n = 686$).

	Episodic Dental Users			Regular Dental Users		
	Nonflossers	Flossers	*P* Value	Nonflossers	Flossers	*P* Value
iCAL≥3 mm (% sites)	56.3 (1.72)	46.2 (4.86)	0.051	38.1 (2.90)	25.7 (1.99)	0.0007
iPD≥4 mm (% sites)	17.8 (1.11)	13.1 (3.13)	0.17	9.46 (1.29)	3.02 (0.88)	<0.0001
Coronal caries (surfaces)	1.64 (0.13)	0.63 (0.38)	0.01	0.23 (0.06)	0.13 (0.04)	0.20
Interproximal caries (surfaces)	0.81 (0.07)	0.39 (0.20)	0.06	0.12 (0.04)	0.05 (0.02)	0.15
Missing teeth (*n*)	15.9 (0.42)	13.4 (1.17)	0.049	13.3 (0.70)	9.70 (0.48)	<0.0001
Missing teeth (*n* excluding third molars)	12.7 (0.38)	10.5 (1.08)	0.054	10.0 (0.67)	6.35 (0.46)	<0.0001

Means adjusted for race, sex, age, diabetes, smoking, education, brushing, and dental utilization; *P* values based on multiple linear regression.
iCAL, interproximal clinical attachment level; iPD, interproximal probing depth.

Table 4. Periodontal Disease Classification Systems by Flossing Behavior ($n = 686$).

PPC-Stages	Nonflossers	Flossers	Chisq/CMH *P* Value
n	462	224	
Stage I (health)	45 (9.7)	90 (40.2)	<0.0001/<0.0001
Stage II Mild	19 (4.1)	12 (5.4)	
Stage III Moderate	4 (0.9)	2 (0.9)	
Stage IV Severe	41 (8.9)	7 (3.1)	
Stage V Mild TL-Hi GI	128 (27.7)	56 (25.0)	
Stage VI Mod TL-Red	121 (26.2)	34 (15.2)	
Stage VII Severe TL	104 (22.5)	23 (10.3)	

Comparison of observed frequencies is based on unadjusted Pearson chi-square tests (first *P* value) and Cochran-Mantel-Haenszel (CMH) tests (second *P* value) adjusted for race, sex, age, diabetes, smoking, education, brushing, and dental utilization. Data are presented as *n* (%).
GI, gingival index; Hi, high; Mod, moderate; Red, reduced periodontium; TL, tooth loss.

Table 5. Percent of Individuals Losing Teeth Over 5-y by Tooth Type and Flossing Habit (Including Individuals Who Became Edentulous) $n = 375$.

	Nonflossers	Flossers	Chisq/CMH *P* Values
All molars retained	147 (61.5)	96 (70.6)	0.08/0.01
1+ molar(s) lost	92 (38.5)	40 (29.4)	
All premolars retained	140 (58.6)	112 (82.4)	<0.0001/0.0002
1+ premolar(s) lost	99 (41.4)	24 (17.7)	
All canines retained	148 (61.9)	125 (91.9)	<0.0001/<0.0001
1+ canine(s) lost	91 (38.1)	11 (8.1)	
All incisors retained	141 (59.0)	119 (87.5)	<0.0001/<0.0001
1+ incisor(s) lost	98 (41.0)	17 (11.5)	

Comparison of observed frequencies is based on unadjusted Pearson chi-square tests (first *P* value) and Cochran-Mantel-Haenszel (CMH) tests (second *P* value) adjusted for race, sex, age, diabetes, smoking, education, brushing, and dental utilization. Data are presented as *n* (%).

premolars ($P < 0.0001$ for each category) with a similar trend for individuals retaining all molars ($P = 0.08$) (Table 5).

In addition, we further analyzed the impact of flossing behavior over the 5-y period in the mean number and type of teeth that were lost. Because we identified a relatively large percentage of dropouts, we present the weighted sensitivity analysis results in Table 6. Unweighted analysis demonstrates nearly identical results (data not shown). Elderly flossers lost fewer teeth across all tooth types (molars, premolars, canines, and incisors), with an average loss of ~1 tooth compared to ~4 teeth lost in nonflossers over the 5-y period ($P < 0.0001$, Table 6). Nonflossers showed 18.7%, 23.9%, and 21.8% increased tooth loss for premolars, canines, and incisors, respectively (Table 6). The most dramatic difference between groups was identified for molars, with 41.6% increase of loss in nonflossers compared to flossers in the 5-y period (Table 6).

Discussion

Older individuals have higher levels of oral disease overall as a reflection of time of exposure to multiple risk factors (Tonetti et al. 2017). Preservation of a functional dentition into old age is possible and provides benefits in the overall quality of life of an individual (Holm-Pedersen et al. 2008). This current study

Table 6. Mean (SE) 5-y Tooth Loss by Tooth Type and Flossing Habit (Including People Who Became Edentulous) *n* = 375.

	Nonflossers (*n* = 239)	Flossers (*n* = 136)	*P* Value	Difference
All Teeth	4.22 (0.34)	1.16 (0.47)	<0.0001	27.49%
Molars	1.20 (0.12)	0.50 (0.14)	<0.0005	41.67%
Premolars	1.28 (0.12)	0.24 (0.16)	<0.0001	18.75%
Canines	0.71 (0.07)	0.17 (0.09)	<0.0001	23.94%
Incisors	1.60 (0.14)	0.35 (0.19)	<0.0001	21.88%

Means adjusted for race, sex, age, diabetes, smoking, education, brushing, and dental utilization via multiple linear regression. Sensitivity analysis accounted for loss to follow-up.

evaluates a preventive oral health behavior in older individuals, which are still relatively neglected in the dental field of the aging world (Tonetti et al. 2017). We provide an assessment of the impact of flossing behavior in community-dwelling people aged <65 y. Our results show that flossing was associated with improved oral health measures. This conclusion is consistent with our previous study that evaluated data from NHANES in >6,000 US adults aged ≥30 y that identified that interdental cleaning was associated with less sites with iCAL≥3 mm, iPD≥4 mm, coronal caries, icaries, and more present teeth compared to individuals identified as non-interdental cleaners (Marchesan et al. 2018). It is important to note that flossing may be heavily influenced by a healthy lifestyle that in turn could be influenced by socioeconomic status and educational levels and other factors that result in an individual's habits. Although our study cannot establish causal relation, multiple difficulties in conducting RCTs to address the benefits of interdental cleaning exist, including allowing time for disease to develop. Until such trials are conducted, longitudinal studies are the best level of evidence available to assess potential risk associated with tooth loss. Our results in no way assume causality of the association we found. It simply means that by adjusting to these social and demographic characteristics, flossing is associated with lower future tooth loss. While the question addressing the practice of the oral regimen was distinct between studies (NHANES analysis addressed all forms of interdental cleaning and the current PDS addressed specifically flossing), both studies concluded that a person who has the habit of cleaning between their teeth at least 1x/week exhibited less oral disease. Therefore, improved oral health measurements were identified in adults (aged ≥30 y) and older adults (aged ≥65 y) that reported having a type of interdental cleaning behavior.

The periodontal disease parameters of iCAL≥3 mm and iPD≥4 mm selected to be used in the present study have been previously used in other studies (Moss et al. 2009; Akinkugbe et al. 2017; Marchesan et al. 2018) and have the advantage of being translated to a clinical meaning independent of disease classifications that change over time. In addition to the periodontal phenotype discussed above, we evaluated the number of individuals distributed among periodontal disease categories based on flossing behavior. For this analysis, we used the PPC-Stages classification (Morelli et al. 2017; Beck et al. 2018; Morelli et al. 2018). Since this classification was recently proposed, there are currently not many studies utilizing these outcomes to evaluate data. Our data show that the majority of flossers were PPC-Stage I (PPC-Stages classification) and majority of nonflossers were PPC-Stage V, VI, and VII. Other cross-sectional studies that evaluated the association of flossing/interdental cleaning with a periodontal disease classification include the analysis of the NHANES 2011–2014 population by Cepeda (Cepeda et al. 2017) and our group (Marchesan et al. 2018). When periodontitis was defined by the Centers for Disease Control and Prevention (CDC) definition (combining mild, moderate, and severe periodontitis), flossing was associated with a modestly lower prevalence of periodontitis (Cepeda et al. 2017). When the PPC-Stages classification was applied to the same NHANES dataset, the majority of individuals were distributed under the PPC-A Health category (Marchesan et al. 2018). Within the limitations of any cross-sectional analysis, our results support an association of healthy periodontal categories and flossing behavior.

In the current study we further stratified the clinical data based on frequency of dental appointments (dental use) as this may affect the oral health of flossers and nonflossers. The results showed that the preventive oral health behaviors of dental visits and flossing correlated with elderly individuals having less oral disease. These results are in accordance to other previous reports (Dolan and Atchison 1993; Yellowitz and Schneiderman 2014; Lee et al. 2019). Recent analysis of 3,255 elderly Koreans (aged 55 to 79 y) identified that toothbrushing frequency and frequent dental visits (within 1 y) were also correlated with number of existing teeth (Lee et al. 2019). Together, the data further support interventions aimed at preserving existing teeth in the elderly population.

Tooth loss is the final negative outcome that can occur with the presence of caries and periodontal disease. Tooth loss can lead to loss of masticatory function, loss of self-esteem, and decreased quality of life. It has been previously shown that the most commonly missing teeth are the molars (Marcus et al. 1996) due to the multirooted nature of the teeth and the difficulty of accessing the teeth. In accordance, our data shows that molars were the tooth type with the greatest flossing benefit seen over the 5-y period. It is important to note that the individuals included in the present study lived in the community. Individuals that moved to a setting of assisted care living (due to physical and/or mental conditions) were excluded from the study. Therefore, the elderly individuals included in the present study were more likely to be capable of being compliant with self-oral hygiene regimens, more similar to younger adults.

Cognitive impairment and dementia that can occur with aging are known to lead to the inability to accurately perform self-care and increase the prevalence of oral disease (Ellefsen et al. 2009; Teng et al. 2016; Delwel et al. 2017).

There are some limitations to our study. Firstly, we must note that the individuals enrolled in this study that initiated in 1988 likely had less access to preventive oral health approaches compared to today. Therefore, the results of this study may not completely represent results from a present-day study. Additionally, loss to follow-up due to death is an undesired outcome that can occur at a higher rate in elderly individuals for obvious reasons and can produce biased results. Therefore, to address this, we included the weighted sensitivity analysis (Table 5). After this adjustment, the results remained nearly identical supporting that elderly flossers lost fewer teeth across all tooth types (molars, premolars, canines, and incisors), with an average loss of ~1 tooth compared to ~4 teeth lost in non-flossers over the 5-y period. Finally, the study is based on the report of the individual regarding their flossing behavior. This approach can influence the hygiene habits of an individual. It also permits individuals to provide untruthful answers, which is not an uncommon behavior observed by dentists and dental hygienists. However, this longitudinal study showed that flossing was negatively related to tooth loss and a false report of flossing would bias in the other direction. Thus, this may be a conservative estimate of the relationship between flossing and tooth loss.

Together, our data show that older individuals who live in the community and floss one or more times per week have lower clinical measures of periodontal disease, fewer caries, and a higher number of teeth. At the 5-y follow-up visit, the average loss for flossers was ~1 tooth compared to ~4 teeth lost for nonflossers. These findings further support flossing behavior as an important oral hygiene habit to prevent oral disease progression in older adults.

Author Contributions

J.T. Marchesan, contributed to data analysis and interpretation, drafted and critically revised the manuscript; K.M. Byrd, T. Morelli, Y. Jiao, contributed to data interpretation, critically revised the manuscript; K. Moss, contributed to data acquisition, analysis, and interpretation, critically revised the manuscript; J.S. Preisser, A.F. Zandona, contributed to data analysis and interpretation, critically revised the manuscript; J. Beck, contributed to conception, design, data acquisition, and interpretation, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

Acknowledgments

The authors would like to thank Dr. Steve Offenbacher for his mentorship and support during the development of this study. The authors would like to thank the following support funding agency/grant numbers—National Institutes of Health K01 DE027087-01 (JTM), K08DE026537 (KMB), K23 DE025093 (TM), and grant R01-09060. The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

ORCID iDs

K.M. Byrd https://orcid.org/0000-0002-5565-0524
J.S. Preisser https://orcid.org/0000-0002-7869-2057
J. Beck https://orcid.org/0000-0001-5415-8311

References

Akinkugbe AA, Slade GD, Barritt AS, Cole SR, Offenbacher S, Petersmann A, Kocher T, Lerch MM, Mayerle J, Volzke H, et al. 2017. Periodontitis and non-alcoholic fatty liver disease, a population-based cohort investigation in the study of health in Pomerania. J Clin Periodontol. 44(11):1077–1087.

Anglemyer A, Horvath HT, Bero L. 2014. Healthcare outcomes assessed with observational study designs compared with those assessed in randomized trials. Cochrane Database Syst Rev. (4):MR000034.

Beck J, Drake C. 1975. Some epidemiologic evidence on the etiology of caries. Community Dent Oral Epidemiol. 3(5):223–227.

Beck JD, Moss KL, Morelli T, Offenbacher S. 2018. In search of appropriate measures of periodontal status: the periodontal profile phenotype (p(3)) system. J Periodontol. 89(2):166–175.

Beck JD, Sharp T, Koch GG, Offenbacher S. 1997. A 5-year study of attachment loss and tooth loss in community-dwelling older adults. J Periodontal Res. 32(6):516–523.

Brown LF, Beck JD, Rozier RG. 1994. Incidence of attachment loss in community-dwelling older adults. J Periodontol. 65(4):316–323.

Cepeda MS, Weinstein R, Blacketer C, Lynch MC. 2017. Association of flossing/inter-dental cleaning and periodontitis in adults. J Clin Periodontol. 44(9):866–871.

Curtis MA, Zenobia C, Darveau RP. 2011. The relationship of the oral microbiotia to periodontal health and disease. Cell Host Microbe. 10(4):302–306.

Delwel S, Binnekade TT, Perez RS, Hertogh CM, Scherder EJ, Lobbezoo F. 2017. Oral health and orofacial pain in older people with dementia: a systematic review with focus on dental hard tissues. Clin Oral Investig. 21(1):17–32.

Dolan TA, Atchison KA. 1993. Implications of access, utilization and need for oral health care by the non-institutionalized and institutionalized elderly on the dental delivery system. J Dent Educ. 57(12):876–887.

Drake CW, Hunt RJ, Beck JD, Koch GG. 1994. Eighteen-month coronal caries incidence in North Carolina older adults. J Public Health Dent. 54(1):24–30.

Ellefsen B, Holm-Pedersen P, Morse DE, Schroll M, Andersen BB, Waldemar G. 2009. Assessing caries increments in elderly patients with and without dementia: a one-year follow-up study. J Am Dent Assoc. 140(11):1392–1400.

Feres M, Teles F, Teles R, Figueiredo LC, Faveri M. 2016. The subgingival periodontal microbiota of the aging mouth. Periodontol 2000. 72(1):30–53.

Graves RC, Beck JD, Disney JA, Drake CW. 1992. Root caries prevalence in Black and White North Carolina adults over age 65. J Public Health Dent. 52(2):94–101.

Guggenheim B, Guggenheim M, Gmur R, Giertsen E, Thurnheer T. 2004. Application of the Zurich biofilm model to problems of cariology. Caries Res. 38(3):212–222.

Hajishengallis G, Darveau RP, Curtis MA. 2012. The keystone-pathogen hypothesis. Nat Rev Microbiol. 10(10):717–725.

Holm-Pedersen P, Schultz-Larsen K, Christiansen N, Avlund K. 2008. Tooth loss and subsequent disability and mortality in old age. J Am Geriatr Soc. 56(3):429–435.

Hujoel PP, Cunha-Cruz J, Banting DW, Loesche WJ. 2006. Dental flossing and interproximal caries: a systematic review. J Dent Res. 85(4):298–305.

Hunt RJ, Drake CW, Beck JD. 1992. *Streptococcus mutans*, lactobacilli, and caries experience in older adults. Spec Care Dentist. 12(4):149–152.

Jepsen S, Blanco J, Buchalla W, Carvalho JC, Dietrich T, Dorfer C, Eaton KA, Figuero E, Frencken JE, Graziani F, et al. 2017. Prevention and control of dental caries and periodontal diseases at individual and population level: consensus report of group 3 of joint EFP/ORCA workshop on the boundaries between caries and periodontal diseases. J Clin Periodontol. 44 Suppl 18:S85–S93.

Jiao Y, Darzi Y, Tawaratsumida K, Marchesan JT, Hasegawa M, Moon H, Chen GY, Nunez G, Giannobile WV, Raes J, et al. 2013. Induction of bone loss by pathobiont-mediated Nod1 signaling in the oral cavity. Cell Host Microbe. 13(5):595–601.

Lee JH, Yi SK, Kim SY, Kim JS, Kim HN, Jeong SH, Kim JB. 2019. Factors related to the number of existing teeth among korean adults aged 55–79 years. Int J Environ Res Public Health. 16(20). pii: E3927.

Listgarten MA, Mayo HE, Tremblay R. 1975. Development of dental plaque on epoxy resin crowns in man. A light and electron microscopic study. J Periodontol. 46(1):10–26.

Loe H, Theilade E, Jensen SB. 1965. Experimental gingivitis in man. J Periodontol. 36:177–187.

Marchesan JT, Morelli T, Moss K, Preisser JS, Zandona AF, Offenbacher S, Beck J. 2018. Interdental cleaning is associated with decreased oral disease prevalence. J Dent Res. 97(7):773–778.

Marcus SE, Drury TF, Brown LJ, Zion GR. 1996. Tooth retention and tooth loss in the permanent dentition of adults: United States, 1988–1991. J Dent Res. 75 Spec No:684–695.

Mc Cord KA, Al-Shahi Salman R, Treweek S, Gardner H, Strech D, Whiteley W, Ioannidis JPA, Hemkens LG. 2018. Routinely collected data for randomized trials: promises, barriers, and implications. Trials. 19(1):29.

Morelli T, Moss KL, Beck J, Preisser JS, Wu D, Divaris K, Offenbacher S. 2017. Derivation and validation of the periodontal and tooth profile classification system for patient stratification. J Periodontol. 88(2):153–165.

Morelli T, Moss KL, Preisser JS, Beck JD, Divaris K, Wu D, Offenbacher S. 2018. Periodontal profile classes predict periodontal disease progression and tooth loss. J Periodontol. 89(2):148–156.

Moss KL, Oh ES, Fisher E, Beck JD, Offenbacher S, White RP Jr. 2009. Third molars and periodontal pathologic findings in middle-age and older americans. J Oral Maxillofac Surg. 67(12):2592–2598.

Sanz M, Beighton D, Curtis MA, Cury JA, Dige I, Dommisch H, Ellwood R, Giacaman RA, Herrera D, Herzberg MC, et al. 2017. Role of microbial biofilms in the maintenance of oral health and in the development of dental caries and periodontal diseases. Consensus report of group 1 of the joint EFP/ORCA workshop on the boundaries between caries and periodontal disease. J Clin Periodontol. 44 Suppl 18:S5–S11.

Socransky SS, Haffajee AD. 2005. Periodontal microbial ecology. Periodontol 2000. 38:135–187.

Takahashi N. 2015. Oral microbiome metabolism: from "who are they?" to "what are they doing?". J Dent Res. 94(12):1628–1637.

Teles R, Teles F, Frias-Lopez J, Paster B, Haffajee A. 2013. Lessons learned and unlearned in periodontal microbiology. Periodontol 2000. 62(1):95–162.

Teng PR, Lin MJ, Yeh LL. 2016. Utilization of dental care among patients with severe mental illness: a study of a national health insurance database. BMC Oral Health. 16(1):87.

Tonetti MS, Bottenberg P, Conrads G, Eickholz P, Heasman P, Huysmans MC, Lopez R, Madianos P, Muller F, Needleman I, et al. 2017. Dental caries and periodontal diseases in the ageing population: call to action to protect and enhance oral health and well-being as an essential component of healthy ageing — consensus report of group 4 of the joint EFP/ORCA workshop on the boundaries between caries and periodontal diseases. J Clin Periodontol. 44 Suppl 18:S135–S144.

Vernon LT, Da Silva APB, Seacat JD. 2017. In defense of flossing: part II-can we agree it's premature to claim flossing is ineffective to help prevent periodontal diseases? J Evid Based Dent Pract. 17(3):149–158.

Vernon LT, Seacat JD. 2017. In defense of flossing: can we agree it's premature to claim flossing is ineffective to prevent dental caries? J Evid Based Dent Pract. 17(2):71–75.

World Health Organization. 2015. World report on ageing and health. Geneva (Switzerland): WHO Press.

Worthington HV, MacDonald L, Poklepovic Pericic T, Sambunjak D, Johnson TM, Imai P, Clarkson JE. 2019. Home use of interdental cleaning devices, in addition to toothbrushing, for preventing and controlling periodontal diseases and dental caries. Cochrane Database Syst Rev. 4(4):CD012018.

Yellowitz JA, Schneiderman MT. 2014. Elder's oral health crisis. J Evid Based Dent Pract. 14 Suppl:191–200.