Vitamin D status and prevalent and incident tooth loss in postmenopausal women: The Buffalo Osteoporosis and Periodontal Disease (OsteoPerio) Study

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Abstract

Background—Vitamin D is hypothesized to reduce risk for tooth loss via its influence on bone health, inflammation, and the immune response. We examined the association between plasma 25-hydroxyvitamin D (25[OH]D) concentrations and the prevalence and 5-year incidence of tooth loss in a cohort of postmenopausal women.

Methods—Participants underwent oral examinations at study baseline (1997–2000) and follow-up (2002–2005) to determine the number of missing teeth and the 5-year incidence of tooth loss, respectively. At both visits women self-reported reasons for each missing tooth. At baseline, 152 women reported no history of tooth loss and 628 were categorized as reporting a history of tooth loss due to periodontal disease (n=70) or caries (n=558) (total n=780). At follow-up, 96, 376, 48, and 328 women were categorized into the aforementioned categories as reasons for incident tooth loss (total n=472). Logistic regression was used to estimate the odds ratios (ORs) and 95% confidence intervals (CIs) for tooth loss by category of baseline 25(OH)D (nmol/L) concentrations. Models were adjusted for age, income, smoking status, frequency of dental visits, waist circumference and recreational physical activity. P for trend was estimated using continuous concentrations of 25(OH)D.

Results—Among women with 25(OH)D ≥ 50 (adequate vitamin D status) compared to <50 nmol/L (deficient/inadequate), the adjusted ORs (95% CI) was 1.24 [0.82–1.87], p-trend=0.049

for the history (prevalence) of tooth loss due to periodontal disease or caries and 1.07 [0.62–1.85], p-trend=0.111 for the incidence of tooth loss due to periodontal disease or caries. No statistically significant association was observed between 25(OH)D and the history or incidence of tooth loss due to periodontal disease. An increased odds of the history of tooth loss due to caries was observed with increasing concentrations of 25(OH)D (p-trend=0.045), but was not confirmed in prospective analyses.

Conclusion—In this cohort of postmenopausal women, the data do not support an association between vitamin D status and tooth loss.

Keywords

Tooth Loss; Periodontitis; Dental Caries; Vitamin D; Women's Health; Postmenopause

While nationally representative data revealed that the prevalence of edentulism has been decreasing in the United States (US) over the past several decades, nearly 23% of adults aged 65 and older were identified as edentulous.[1] Edentulism has a negative impact on quality of life, nutritional status, and overall health, and thus represents a serious ongoing public health concern.[2, 3] Periodontal disease, together with caries, remains the primary cause of edentulism among the elderly.[4, 5]

Vitamin D has been hypothesized to prevent development of periodontal disease,[6] caries,[7] and tooth loss.[8–10] Vitamin D's essential role in calcium homeostasis[11], along with its anti-inflammatory[12] and anti-microbial properties,[13] may protect against alveolar bone loss and subsequent tooth loss. Previous research on vitamin D and tooth loss is limited. The few studies that have examined the association suggest that adequate vitamin D status may prevent tooth loss.[8–10] To the best of our knowledge, there have been no studies of the association between the blood biomarker for vitamin D status, 25-hydroxyvitamin D (25[OH]D), and specific reasons for tooth loss (caries versus periodontal disease), in older postmenopausal women who may be particularly vulnerable to both vitamin D insufficiency and advanced periodontitis.

Using data from the Osteoporosis and Periodontal Disease Study (OsteoPerio), an ancillary study of the Women's Health Initiative (WHI) Observational Study (OS), we investigated the association between plasma 25(OH)D concentrations and the history of tooth loss (prevalence) assessed at baseline (1997–2000) and the 5-year incidence of tooth loss assessed at follow-up (2002–2005). The outcomes assessed were tooth loss due to periodontal disease, caries, or either.

MATERIALS AND METHODS

Study Sample

The OsteoPerio study is an ancillary study of the WHI OS of postmenopausal women.[14, 15] Participants were enrolled from the Buffalo, NY WHI clinic center from 1997–2000 to examine the association between osteoporosis and periodontal disease.[16] The OsteoPerio baseline data collection coincided with the WHI OS third year visit. There were 1,362 participants.[16] Women were excluded if they had inadequate oral X-rays (n=16) or

incomplete study questionnaires (n=5). Of the remaining 1,341 participants, 407 were excluded because they lacked plasma samples for 25(OH)D assessment and one women with an extremely high 25(OH)D value (530 nmol/L) was excluded.

Sample for Cross-Sectional Study of History of Tooth Loss (Prevalence)—A cross-sectional analysis was conducted to examine the association between baseline 25(OH)D concentrations and history of tooth loss assessed at baseline. Of the remaining 933 participants, one woman was excluded due to missing baseline data on tooth loss. Seventy-five women were excluded because they self-reported a history of tooth loss for reasons other than periodontal disease or caries. An additional 77 women were excluded because of missing pertinent covariate data: annual family income (n=53), waist circumference (n=24) and recreational physical activity (n=16). This left 780 women of whom 152 had no history of tooth loss due to any reasons and 628 had a history of tooth loss due to either periodontal disease or caries. There were 70 women with a history of at least one tooth lost due to periodontal disease (with or without teeth lost to caries) and 558 with a history of at least one tooth lost due to caries (with no teeth lost due to periodontal disease) (Figure 1).

Sample for Prospective Study of Incident Tooth Loss—A prospective analysis was conducted to examine the association between baseline 25(OH)D concentrations and the incidence of tooth loss from baseline to the 5-year follow-up. Of the 933 participants with 25(OH)D concentrations at baseline, 702 attended the OsteoPerio Study follow-up exam. Women were excluded from the prospective analysis if they were missing follow-up data on self-reported reasons for tooth loss (n=3) or because they self-reported reasons for incident tooth loss other than periodontal disease or caries (n=187). An additional 40 women were excluded because of missing pertinent covariate data: annual family income (n=25), waist circumference (n=14) and recreational physical activity (n=8). This left 472 women, of whom 96 had no incident tooth loss due to any reasons and 376 had incident tooth loss due to either periodontal disease or caries. There were 48 women with at least one incident tooth lost over follow-up due to periodontal disease (with or without incident tooth loss to caries) and 328 with at least one incident tooth lost due to caries (with no teeth lost due to periodontal disease)

For cross-sectional and prospective analyses examining associations between vitamin D intake and tooth loss, women were further excluded for missing data on either dietary or supplemental vitamin D intake at study baseline resulting in slightly smaller analytic samples than those with 25(OH)D (n=774 for the cross-sectional analyses and n=470 for the prospective analyses).

The University of Buffalo Institutional Review Board approved the study protocol and all study participants have signed informed consent.

Assessment of vitamin D status

Fasting blood samples were collected from participants at the OsteoPerio baseline visit, processed and stored at −80°C. Samples were assessed for 25(OH)D by competitive chemiluminescence assay[§], as previously described.[17] We adjusted 25(OH)D concentrations for the season of blood draw. Residuals were computed from the regression of 25(OH)D on

the day of the year of blood draw and added to the sample mean for 25(OH)D.[6] We used season-adjusted 25(OH)D concentrations in our analyses.

The estimated average daily dietary intake of vitamin D (IU/day), calcium (mg/day), and sugar (g/day) over the past three months was assessed from a previously validated, self-administered modified Block food frequency questionnaire (FFQ)[18] given at the WHI OS year 3 follow-up (1997-200) which coincided with OsteoPerio baseline. Vitamin D and calcium supplement intake over the past 30 days was assessed at OsteoPerio baseline, including information on brand name, dosage, quantity, frequency and duration of intake. Total vitamin D and calcium intake was estimated by summing daily intake from dietary and supplement sources.

Oral Health Exam

An oral health exam, including radiographs, was performed on each participant. Trained and calibrated dental examiners assessed the number of teeth present and recorded the self-reported reasons for each tooth missing (excluding third molars). Reasons for missing teeth could include caries, periodontal disease, fracture/accident, root canal, orthodontic reasons, unerupted, congenitally missing, implant, retained root, or unable to determine. For these analyses, women were defined as having *no tooth loss* if they reported no missing teeth due to any reasons (retained all 28 natural teeth, excluding third molars) and as having *any tooth loss* if they reported losing at least one tooth due to periodontal disease or caries. Women were defined as having *tooth loss due to periodontal disease* if they reported losing at least one tooth due to periodontal disease, but could have reported a tooth lost to caries. Women were defined as having *tooth loss due to caries* if they reported losing at least one tooth due to caries, but no teeth lost due to periodontal disease. Validation of self-reported reasons for tooth loss has been reported in a previous publication.[19]

Covariates Assessment

At the OsteoPerio clinic visit the women's height and weight was measured according to standardized protocols. Body mass index (BMI) (kg/m^2) was calculated. Women completed self-reported questionnaires to assess age at visit, race/ethnicity, education level, marital status, annual household income and lifestyle information regarding smoking habits, alcohol intake, diet and physical activity.[16, 20] Personal and family health history data and information on history of medication use, such as hormone therapy and bone drug use was collected. Oral health behavior data, such as frequency of tooth brushing, frequency of dental visits and frequency of flossing were obtained via a self-reported questionnaire.

Statistical Analyses

Guided by the Institute of Medicine's (IOM) report on vitamin D and calcium,[21] we divided the study population into four vitamin D status categories using 25(OH)D concentrations in nmol/L (<30, 30 to <50, 50 to <75, and 75) and two broader categories (<50 and 50). The IOM considers 25(OH)D concentrations <30 nmol/L as deficient vitamin D status and concentrations <50 nmol/L as deficient or inadequate vitamin D status.[21] Vitamin D intake

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§Liaison 25-OH Vitamin D Total Assay, DiaSorin, Stillwater, MN.

(IU/day) was categorized as <400, 400 to <600 and 600 as well as two broader categories (<600 and 600). The IOM's Recommended Dietary Allowance (RDA) for vitamin D is 600 IU/day.[21]

We investigated if potential periodontal disease risk factors were associated with 25(OH)D concentrations and history of tooth loss at baseline. We used t-tests and ANOVAs to test if means of continuous variables differed across categories of 25(OH)D and tooth loss and Chi-square and Fischer's exact tests to investigate if the distribution of categorical variables varied by category of 25(OH)D and tooth loss.

Logistic regression was used to estimate odds ratios (ORs) and 95% confidence intervals (95% CIs) for the history of any tooth loss, tooth loss due to periodontal disease, and tooth loss due to caries by the four categories of 25(OH)D, with the referent category of deficient vitamin D status (<30 nmol/L), and by the three categories of total vitamin D intake, with the referent category of <400 IU/day. Because our prospective analyses were limited by sample size, we estimated the ORs and 95% CIs for the incidence of any tooth loss, tooth loss due to periodontal disease, and tooth loss due to caries by the two categories of 25(OH)D, with the referent category of deficient or inadequate vitamin D status (<50 nmol/L), and by the two categories of vitamin D intake, with the referent category of <600 IU/day. To compare the results between the cross-sectional and prospective analyses, we also repeated the cross-sectional analyses with the same dichotomized exposure categories used in the prospective analyses. P for trend was estimated using continuous concentrations of 25(OH)D or total intake of vitamin D.

We investigated whether certain periodontal disease risk factors were confounding the crude associations between vitamin D status and the history of any tooth loss, tooth loss due to periodontal disease, and tooth loss due to caries. Factors associated with both vitamin D status and tooth loss at p-values 0.20 were considered as potential confounders in multivariable models. Potential confounders were added to the crude models separately to assess their influence on the ORs in a step-wise fashion and included in the multivariable model if they changed the OR 10% or more. We adjusted for the most inclusive group of confounders from multivariable models built for the odds of any tooth loss, tooth loss due to periodontal disease, and tooth loss due to caries. Age, annual family income, smoking status, frequency of dental visits, and waist circumference influenced ORs the greatest (>10%). We also adjusted for recreational physical activity as it appeared to confound the model, but not to the extent as the other noted covariates. The same model was used for our cross-sectional analyses of history of tooth loss and vitamin D intake as well as for all prospective analyses. For all analyses, P-values (two-tailed) of <0.05 were considered statistically significant.

We explored if the association between any tooth loss and 25(OH)D concentrations was modified by total calcium intake in either the cross-sectional or prospective analyses. Vitamin D status was defined as deficient/inadequate [25(OH)D <50 nmol/L] and adequate [25(OH)D 50 nmol/L]. Categories of calcium intake were chosen based on the IOM's Recommended Dietary Allowance (RDA)[21] of 1200 mg/day for females 51 years and older: <1200 and 1200 mg/day. We examined the odds of any tooth loss by the joint effects of total calcium intake and vitamin D status using calcium intake <1200 mg/day and

25(OH)D<50 nmol/L as the referent group. If the p-value for the interaction product term added to the multivariable model was <0.10 we considered the multiplicative interaction statistically significant.

We performed all analyses by using a statistical software program.[**]

RESULTS

In our sample 65.8% (n=513) of women had adequate vitamin D status (50 nmol/L) and 9.0% (n=70) were deficient (<30 nmol/L) (Table 1). Women with deficient compared to adequate status were, on average, older had lower annual family income and were less likely to be Caucasian. The highest percentage of current smokers was in vitamin D deficient women. On average, women with deficient status had larger BMIs, waist circumferences, and waist to hip ratios, reported less recreational physical activity, lower vitamin D intake, and a lower alcohol consumption. There was a greater proportion of never users of hormone therapy among women with deficient vitamin D status than in women with inadequate or adequate vitamin D status. The greatest percentage of bone drugs users was among women with adequate vitamin D status (50 to <75 nmol/L) and the lowest among those with inadequate status. Women with deficient vitamin D status were more likely to have osteoporosis and women with deficient or inadequate status were more likely to have diabetes, as compared to women with adequate status. Women with deficient vitamin D status were also less likely to visit the dentist and brush their teeth as frequently, and had, on average, a lower number of teeth present compared to women with adequate status. Results of participant's characteristics by history of tooth loss are shown in Supplemental Table 1.

Cross-Sectional Analysis of Vitamin D Status and History of Tooth Loss

The adjusted OR [95% CI] for the history of any tooth loss was 1.53 [0.67, 3.50] among women with an adequate (25[OH]D 75 nmol/L) compared to deficient (25[OH]D <30 nmol/L) vitamin D status (Table 2) and 1.24 [0.82–1.87] for women with an adequate (25[OH]D 50 nmol/L) compared to deficient or inadequate (25[OH]D <50 nmol/L) vitamin D status. The p for trend for was 0.049. We observed no association between vitamin D status and tooth loss due to periodontal disease (adjusted OR [95% CI] =1.10 [0.32, 3.76] for adequate [25[OH]D 75 nmol/L] compared to deficient [25[OH]D <30 nmol/L] vitamin D status with a p-for trend=0.189) (Table 2). Similar to the results for any tooth loss, we observed an increased odds for tooth loss due to caries (adjusted OR [95% CI]=1.72 [0.74, 4.00] for adequate [25[OH]D 75 nmol/L] compared to deficient [25[OH]D <30 nmol/L] vitamin D status with a p-for trend=0.045). Results were consistent when we estimated the odds of the history of tooth loss due to periodontal disease or caries among women with 25(OH)D concentrations defined as adequate (25[OH]D 50 nmol/L) compared to deficient or inadequate (25[OH]D <50 nmol/L) (data not shown). Adjustment of the caries analyses for sugar intake, a potential risk factor for caries,[22, 23] did not influence results (data not shown). The association between 25(OH)D and history any tooth loss was not modified by total calcium intake (Supplemental Table 2).

[**]Version 9.2 for Windows, SAS Institute, Inc., Cary, NC.

We also examined the association between the history of any tooth loss and vitamin D status defined by total intake of vitamin D. Adjusted analyses showed a lower, but not statistically significant, odds of a history of any tooth loss, tooth loss due to periodontal disease, and tooth loss due to caries among women with high (600 IU) compared to low (<400 IU) total vitamin D intake. Analyses using continuous intake of total vitamin D showed a statistically significantly lower odds of the history of any tooth loss and tooth loss due to caries with increasing vitamin D intake (p-trend=0.037 and 0.048, respectively).

Prospective Analysis of Vitamin D Status and Incident Tooth Loss

There was no statistically significant association observed between vitamin D status defined by 25(OH)D or total vitamin D intake and the incidence of any tooth loss, tooth loss due to periodontal disease or tooth loss due to caries (Table 3). The association between 25(OH)D and incidence of any tooth loss was not modified by total calcium intake (Supplemental Table 2).

DISCUSSION

In this study of postmenopausal women, our data do not support a protective association between 25(OH)D and the prevalence of, or 5-year incidence of, tooth loss due to periodontal disease or caries. Further, our results were not modified by total calcium intake. We originally hypothesized that having adequate vitamin D status, as defined by 25(OH)D concentrations, would reduce risk of tooth loss due to periodontal disease through its anti-inflammatory, immunologic and bone related properties,[12, 13, 24–27] however, our study results do not support this hypothesis.

Previous studies do support a role of vitamin D in preventing tooth loss.[8–10] Results from a 3-year randomized, placebo controlled supplementation trial in elderly individuals demonstrated that calcium and vitamin D supplementation was associated with lower odds of self-reported tooth loss.[8] This study was limited by its small sample size (N=145) and inability to separate the effects of calcium from vitamin D supplementation. A 20-year cohort study of male health professions found a significant inverse association between a predicted 25(OH)D score and incident, self-reported tooth loss.[9] Predictive scores for 25(OH)D do not strongly correlated with vitamin D status from 25(OH)D measures and may reflect a healthy lifestyle score rather than vitamin D status.[28] The prospective, population-based Study of Health in Pomerania[10] showed that higher serum 25(OH)D concentrations were associated with reduced risk for tooth loss, assessed by dental examiners. This study was conducted in Germany where foods are not fortified for vitamin D.[29] They had a greater prevalence of participants with 25(OH)D<50 nmol/L (60% versus 34% in our study). In these studies,[8–10] reasons for tooth loss, which could have provided additional understanding of the association between the vitamin D and tooth loss, were not assessed.

We hypothesized that adequate vitamin D status would prevent against tooth loss due to caries based on its anti-microbial properties,[7, 30] however, in our study we observed an increased odds of the history of tooth loss due to caries in women with adequate compared to deficient vitamin D status (p-for trend=0.045). Adjustment of our multivariable analyses for recreational physical activity and waist circumference, which are strong predictors of

vitamin D status,[28] may have led to over-adjustment, and further strengthened rather than attenuated the observed direct association with tooth loss due to caries.

A recent, systematic meta-analyses of studies on vitamin D and different health outcomes suggested a possible protective association between 25(OH)D and dental caries in children.[31] Literature on the association between vitamin D and risk of dental caries in adult populations is scarce. Previous studies from the 1950's observed inverse associations between sun exposure, as a proxy for vitamin D status, and caries, but these studies were limited to males.[32, 33] We speculate that our observed increased odds of the history of tooth loss due to caries was spurious and hypothesize that we did not observe a protective association because tooth loss due to caries likely occurred at an earlier stage in life than the postmenopausal period.[31] We acknowledge that vitamin D status during the postmenopausal period may not strongly correlate with status at an earlier stage in life. We also propose that the observed increased odds of the history of any tooth loss is explained by the large proportion of women who reported a history of tooth loss due to caries. Of the 628 women defined as having a history of any tooth loss, 558 (88.9%) reported a history of losing teeth due to caries. This may be due to over-reporting of tooth loss due to caries as suggested by our self-reported tooth loss validation study.[19] At the same time, our prospective analysis of the association between vitamin D status and incident tooth loss due to caries found no statistically significant associations and does not support the association observed in the cross-sectional analysis.

We also explored the association between tooth loss and total vitamin D intake from foods and supplements. Our cross-sectional analyses found an inverse relationship between total vitamin D intake and the history of any tooth loss and tooth loss due to caries. Our prospective analyses did not confirm these findings, however the results did trend towards a decreased odds of any incident tooth loss or incident tooth loss due to caries with higher compared to lower total vitamin D intake. As these results differ from our findings with 25(OH)D, it is possible that they reflect a protective effect of healthy diets or supplement intake on tooth loss among postmenopausal women, rather than current vitamin D status.

Taken together, our study results correlate with other recent findings within the Buffalo OsteoPerio Study where an inverse association between 25(OH)D and gingival bleeding, an acute measure of periodontal inflammation has been observed,[6] and no association between 25(OH)D and alveolar crestal height, a chronic measure of oral bone loss, or changes in alveolar crestal height over time has been reported.[6, 34] Our study's findings in the OsteoPerio study suggest that vitamin D may be more influential during the earlier, acute phase of periodontal disease than in prevention of chronic periodontal disease and subsequent tooth loss. It is also possible that our follow-up time was not long enough to observe an association between vitamin D status and incident tooth loss.

Our study may be restricted by a lack of a sufficient sample size to detect a more precise relationship between vitamin D status and tooth loss due to periodontal disease. Additionally, we had a low percentage of women with deficient vitamin D status (9% of 780). The OsteoPerio sample is primarily Caucasian, well-educated women with higher socioeconomic status and good self-reported oral hygiene practices and overall health,

limiting the generalizability to other populations. The self-report of the reasons for tooth loss may have led to misclassification. At the same time, standardized protocols were utilized to minimize measurement error in data collection. These data were obtained from the participants during a comprehensive, standardized oral examination by trained oral health examiners. It is unlikely that misclassification of tooth loss or reasons for tooth loss was differential by vitamin D status.

Important strengths of our study include the use of plasma 25(OH)D, a biomarker which reflects vitamin D from all sources including sunlight, diet and supplements. Our study sample is a relatively large group of postmenopausal women, who are at risk for both vitamin D insufficiency and advanced periodontitis. We also had extensive information on potential confounders of the association between vitamin D status and tooth loss. We were able to explore the association between vitamin D status and reason for tooth loss, which was not previously done in other studies, and we were able to examine these associations at baseline and prospectively over 5 years of follow-up.

CONCLUSION

The results of our presented study suggest that, in a sample of US postmenopausal women, vitamin D status, assessed by 25(OH)D concentrations or vitamin D intake, is not associated with tooth loss due to periodontal disease or caries.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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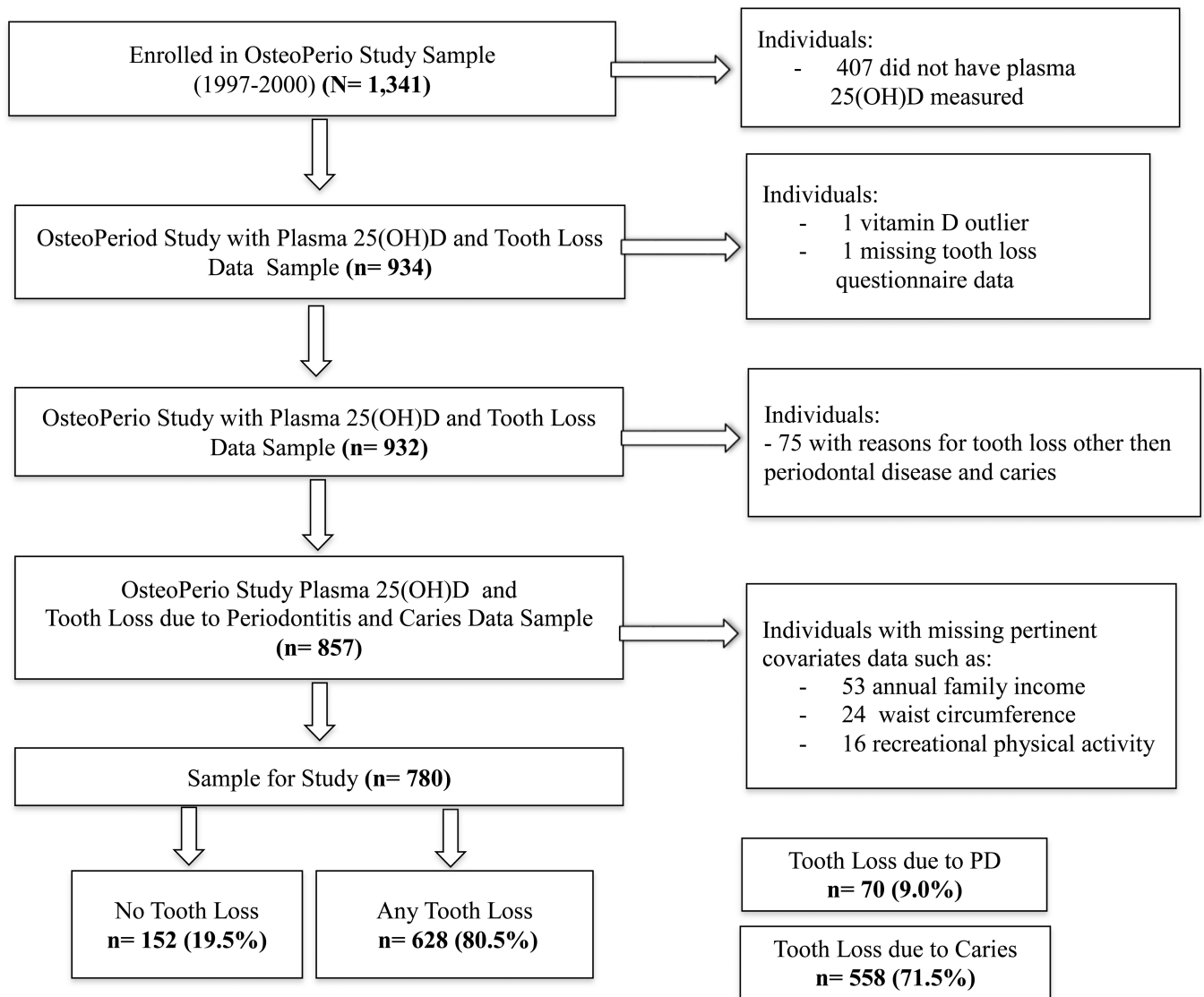
Figure 1.

Flowchart of study participants. There are 152 women who self-reported never losing any teeth (women retaining all 28 natural teeth, excluding third molars). There are 628 women who self-reported tooth loss due to periodontal disease or caries. There are 70 women who self-reported tooth loss due to periodontal disease (with or without tooth loss due to caries) and there are 558 women who self-reported tooth loss due to caries (with no tooth loss due to periodontal disease).

Table 1

Characteristics by clinically defined categories of plasma 25(OH)D concentrations (nmol/L) at study baseline (1997–2000): The Women's Health Initiative Osteoporosis and Periodontal Disease (OsteoPerio) Study (n=780)

Characteristic	Deficient (<30) n = 70 (9.0%)	Inadequate (30 to < 50) n = 197 (25.3%)	Adequate (50 to < 75) n = 338 (43.3%)	Adequate (75) n = 175 (22.4%)	p-value*
Demographic Factors					
Age (years), mean ± SD[†]	68.3 ± 7.3	66.9 ± 7.2	67.1 ± 7.1	65.3 ± 7.1	0.007
Race/Ethnicity, n (% Caucasian)	66 (94.3)	187 (94.9)	333 (98.5)	172 (98.3)	0.028
Education, n (%)					0.237
High school	20 (29.4)	45 (22.8)	74 (22.0)	27 (16.0)	
College	31 (45.6)	86 (43.7)	157 (46.7)	77 (45.6)	
Post-graduate	17 (25.0)	66 (33.5)	105 (31.3)	65 (38.5)	
Annual Family Income, n (%)					0.015
< 35, 000	37 (52.9)	86 (43.7)	139 (41.1)	56 (32.0)	
35, 000	33 (47.1)	111 (56.4)	199 (58.9)	119 (68.0)	
Lifestyle Factors					
Smoking Status, n (%)					<0.001
Never	35 (50.0)	109 (55.3)	177 (52.4)	94 (53.7)	
Past	26 (37.1)	81 (41.1)	156 (46.2)	76 (43.4)	
Current	9 (12.9)	7 (3.6)	5 (1.5)	5 (2.9)	
Pack Years of Smoking, n (%)					0.065
Never	35 (50.0)	109 (56.8)	177 (53.6)	94 (54.3)	
Light (< 8)	7 (10.0)	20 (10.4)	61 (18.5)	28 (16.2)	
Moderate (8 to <26)	9 (12.9)	33 (17.9)	47 (14.2)	29 (16.7)	
Heavy (26)	19 (27.1)	30 (15.6)	45 (13.6)	22 (12.7)	
Body Mass Index (kg/m², mean ± SD	28.1 ± 5.7	28.5 ± 5.3	26.2 ± 4.6	25.4 ± 4.8	<0.0001
Waist Circumference (cm), mean ± SD	89.4 ± 13.6	89.0 ± 12.5	83.5 ± 11.4	80.1 ± 11.2	<0.0001
Waist to Hip Ratio, mean ± SD	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	<0.0001
Recreational Physical Activity, (MET hrs/wk)[‡], n (%)					<0.0001
None	23 (32.9)	35 (17.8)	42 (12.4)	21 (12.0)	
10	27 (38.6)	74 (37.6)	115 (34.0)	50 (28.6)	

Characteristic	Deficient (<30) n = 70 (9.0%)	Inadequate (30 to < 50) n = 197 (25.3%)	Adequate (50 to < 75) n = 338 (43.3%)	Adequate (75) n = 175 (22.4%)	p-value*
Vitamin D status defined by categories of 25(OH)D					
> 10	20 (28.6)	88 (44.7)	181 (53.6)	104 (59.4)	
Vitamin D Intake (IU/day), mean ± SD					
Dietary Intake	172.2 ± 120.9	202.1 ± 140.7	217.3 ± 144.6	203.2 ± 119.4	0.081
Supplemental Intake	103.4 ± 183.0	237.3 ± 244.9	354.9 ± 281.2	425.6 ± 308.0	< 0.0001
Total Intake§	277.1 ± 221.1	440.8 ± 281.3	571.2 ± 320.1	628.8 ± 319.9	< 0.0001
Alcohol Consumption (servings/week), mean ± SD	2.8 ± 5.2	2.6 ± 4.8	3.0 ± 4.3	4.0 ± 5.2	0.035
Hormone Therapy Use, n (%)					0.003
Never	36 (51.4)	71 (36.0)	105 (31.1)	47 (26.9)	
Past	14 (20.0)	43 (21.8)	71 (21.0)	31 (17.7)	
Current	20 (28.6)	83 (42.1)	162 (47.9)	97 (55.4)	
Current Bone Drugs Use¶, n (%Yes)	6 (8.6)	10 (5.1)	39 (11.6)	12 (6.9)	0.054
Comorbid Conditions					
Worst site T-score, n (%)					0.003
Normal (T −1.0);	11 (15.7)	31 (15.7)	49 (14.5)	32 (18.3)	
Low bone density (−2.5<T<−1.0)	17 (24.3)	91 (46.2)	163 (48.2)	88 (50.3)	
Osteoporosis (T −2.5)	42 (60.0)	75 (38.1)	126 (37.3)	55 (31.4)	
Self-reported History of Diabetes, n (%Yes)	5 (7.1)	18 (9.1)	10 (3.0)	3 (1.7)	0.001
Self-reported History of Thyroid Disease, n (% Yes)	19 (27.1)	36 (18.3)	74 (21.9)	33 (18.9)	0.373
Oral Health Measures					
Days Since Last Dental Cleaning, n (% >90 days)	46 (65.7)	121 (61.4)	212 (62.7)	106 (60.6)	0.884
Frequency of Dental Visits, n (%)					0.016
Never or only with a Problem	15 (21.4)	20 (10.2)	26 (7.7)	12 (6.9)	
Once a year	9 (12.8)	32 (16.2)	46 (13.6)	25 (14.3)	
More than once a year	46 (65.7)	145 (73.6)	266 (78.7)	138 (78.9)	
Frequency of Flossing, n (%)					0.145
Not every day	13 (18.6)	43 (21.8)	50 (14.8)	36 (20.7)	
Once a week	4 (5.7)	17 (8.6)	36 (10.7)	19 (10.9)	
More than once a week	27 (38.6)	63 (32.0)	100 (29.6)	40 (23.0)	
Everyday	26 (37.1)	74 (37.6)	152 (45.0)	79 (45.4)	

Characteristic	Deficient (<30) n = 70 (9.0%)	Inadequate (30 to < 50) n = 197 (25.3%)	Adequate (50 to <75) n = 338 (43.3%)	Adequate (75) n = 175 (22.4%)	p-value [*]
Vitamin D status defined by categories of 25(OH)D					
Frequency of Tooth Brushing, n (%)					0.013
Not every day	2 (2.9)	3 (1.5)	1 (0.3)	1 (0.6)	
One time a day	24 (34.3)	57 (28.9)	64 (18.9)	42 (24.0)	
Two times a day	31 (44.3)	104 (52.8)	200 (59.2)	88 (50.3)	
More than two times a day	13 (18.6)	33 (16.8)	73 (21.6)	44 (25.1)	
Number of Teeth Present, mean ± SD	20.5 ± 7.3	23.2 ± 5.3	23.3 ± 5.3	23.9 ± 4.1	< 0.0001

[*]
P-values from ANOVA for continuous variables and Chi-square and Fisher's exact test for categorical variables.

[†]SD: standard deviation.

[‡]MET: metabolic equivalents of task (1 MET is equivalent to a metabolic rate consuming 1 kilocalorie per kilogram of body weight per hour).

[§]Dietary and supplemental vitamin D intake together.

[¶]Current bone drug use include women taking bone drugs Alendronate or Calcitonin.

Table 2

Odds ratios (OR) and 95% confidence intervals (95% CIs) for prevalent tooth loss by vitamin D status determined at study baseline (1997–2000): The Women's Health Initiative Osteoporosis and Periodontal Disease (OsteoPerio) Study

	Vitamin D status defined by categories of 25(OH)D (nmol/L) (n=780)				
	Deficient (<30) OR (95% CI)	Inadequate (30 to <50) OR (95% CI)	Adequate (50 to <75) OR (95% CI)	Adequate (≥75) OR (95% CI)	p-for trend [*]
Any Tooth Loss[†]					
N outcome/total	59/70	156/197	267/338	146/175	
Unadjusted model	1.0	0.71 (0.34–1.47)	0.70 (0.35–1.41)	0.94 (0.44–2.00)	0.779
Age adjusted model	1.0	0.77 (0.37–1.61)	0.75 (0.37–1.51)	1.15 (0.53–2.48)	0.361
Multivariable model[‡]	1.0	0.81 (0.37–1.74)	0.88 (0.42–1.87)	1.53 (0.67–3.50)	0.049
Tooth Loss due to Periodontal Disease[§]					
N outcome/total	11/22	14/55	30/101	15/44	
Unadjusted model	1.0	0.34 (0.12–0.96)	0.42 (0.17–1.08)	0.52 (0.18–1.47)	0.799
Age adjusted model	1.0	0.37 (0.13–1.08)	0.46 (0.17–1.24)	0.73 (0.24–2.19)	0.626
Multivariable model[‡]	1.0	0.39 (0.12–1.26)	0.60 (0.20–1.80)	1.10 (0.32–3.76)	0.189
Tooth Loss due to Caries[‖]					
N outcome/total	48/59	142/183	237/308	131/160	
Unadjusted model	1.0	0.79 (0.38–1.67)	0.77 (0.38–1.55)	1.04 (0.48–2.23)	0.714
Age adjusted model	1.0	0.86 (0.40–1.83)	0.83 (0.40–1.71)	1.26 (0.57–2.76)	0.341
Multivariable model[‡]	1.0	0.93 (0.43–2.05)	1.02 (0.47–2.19)	1.72 (0.74–4.00)	0.045

	Vitamin D status defined by categories of total vitamin D intake (IU/day) (n=774)			
	<400 OR (95% CI)	400 to < 600 OR (95% CI)	≥600 OR (95% CI)	p-for trend [*]
Any Tooth Loss[¶]				
N outcome/total	236/284	145/179	242/311	
Unadjusted model	1.0	0.87 (0.53–1.41)	0.71 (0.47–1.08)	0.019
Age adjusted model	1.0	0.88 (0.54–1.44)	0.76 (0.50–1.1.5)	0.029
Multivariable model[‡]	1.0	1.01 (0.61–1.67)	0.79 (0.52–1.21)	0.037
Tooth Loss due to Periodontal Disease[#]				

				P
N outcome/total	30/78	16/50	24/93	
Unadjusted model	1.0	0.75 (0.36–1.59)	0.56 (0.29–1.07)	0.056
Age adjusted model	1.0	0.76 (0.35–1.65)	0.62 (0.32–1.22)	0.106
Multivariable model[‡]	1.0	0.87 (0.37–2.04)	0.53 (0.25–1.12)	0.080
Tooth Loss due to Caries [**]				
N outcome/total	206/254	129/163	218/287	
Unadjusted model	1.0	0.88 (0.54–1.45)	0.74 (0.49–1.12)	0.028
Age adjusted model	1.0	0.91 (0.55–1.50)	0.78 (0.51–1.19)	0.040
Multivariable model[‡]	1.0	1.03 (0.62–1.72)	0.82 (0.53–1.27)	0.048

[*] Logistic regression was used to calculate p for linear trend using continuous 25(OH)D plasma concentrations or total vitamin D intake.

[†] There are 780 women in this analysis, of whom 628 had any history of tooth loss (due to periodontal disease, caries, or both), and 152 had no history of tooth loss due to any reasons.

[‡] Multivariable model: adjusted for age, annual family income, smoking status, frequency of dental visits, waist circumference and recreational physical activity.

[§] There are 222 women in this analysis, of whom 70 had a history of tooth loss due to periodontal disease (with or without a history of tooth loss due to caries), and 152 had no history of tooth loss due to periodontal disease, and 152 had no history of tooth loss due to any reasons.

[||] There are 710 women in this analysis, of whom 558 had a history of tooth loss due to caries and no history of tooth loss due to periodontal disease, and 152 had no history of tooth loss due to any reasons.

[¶] There are 774 women in this analysis, of whom 623 had any history of tooth loss (due to periodontal disease, caries, or both), and 151 had no history of tooth loss due to any reasons.

[#] There are 221 women in this analysis, of whom 70 had a history of tooth loss due to periodontal disease (with or without a history of tooth loss due to caries), and 151 had no history of tooth loss due to periodontal disease, and 151 had a history of tooth loss due to any reasons.

[**] There are 704 women in this analysis, of whom 553 had a history of tooth loss due to caries and no history of tooth loss due to periodontal disease, and 151 had a history of tooth loss due to any reasons.

Table 3

Odds ratios (OR) and 95% confidence intervals (95% CIs) for incident tooth loss by vitamin D status determined at study baseline (1997–2000)): The Women's Health Initiative Osteoporosis and Periodontal Disease (OsteoPerio) Study

	Vitamin D status defined by categories of 25(OH)D (nmol/L) (n=472)		
	Deficient/Inadequate (<50) OR (95% CI)	Adequate (50) OR (95% CI)	p-for trend[*]
Any Tooth Loss[†]			
N outcome/total	126/156	250/316	
Unadjusted model	1.0	0.90 (0.56–1.46)	0.765
Age adjusted model	1.0	0.93 (0.57–1.51)	0.515
Multivariable model[‡]	1.0	1.07 (0.62–1.85)	0.111
Tooth Loss due to Periodontal Disease[§]			
N outcome/total	13/43	35/101	
Unadjusted model	1.0	1.22 (0.57–2.64)	0.671
Age adjusted model	1.0	1.33 (0.60–2.96)	0.368
Multivariable model[‡]	1.0	1.61 (0.67–3.89)	0.099
Tooth Loss due to Caries[//]			
N outcome/total	113/143	215/281	
Unadjusted model	1.0	0.87 (0.53–1.41)	0.804
Age adjusted model	1.0	0.89 (0.54–1.47)	0.586
Multivariable model[‡]	1.0	1.01 (0.58–1.77)	0.142

	Vitamin D status defined by categories of total vitamin D intake (IU/day) (n=470)		
	< 600 OR (95% CI)	600 OR (95% CI)	p-for trend[*]
Any Tooth Loss[¶]			
N outcome/total	224/276	151/194	
Unadjusted model	1.0	0.82 (0.52–1.28)	0.292
Age adjusted model	1.0	0.86 (0.54–1.36)	0.367
Multivariable model[‡]	1.0	0.90 (0.56–1.44)	0.567
Tooth Loss due to Periodontal Disease[#]			
N outcome/total	26/78	22/65	
Unadjusted model	1.0	1.02 (0.51–2.05)	0.838
Age adjusted model	1.0	1.35 (0.64–2.86)	0.566
Multivariable model[‡]	1.0	0.99 (0.43–2.28)	0.956
Tooth Loss due to Caries[**]			
N outcome/total	198/250	129/172	
Unadjusted model	1.0	0.79 (0.50–1.25)	0.246
Age adjusted model	1.0	0.82 (0.51–1.31)	0.304
Multivariable model[‡]	1.0	0.87 (0.54–1.42)	0.534

[*] Logistic regression was used to calculate p for linear trend using continuous 25(OH)D plasma concentrations or total vitamin D intake.

[†] There are 472 women in this analysis, of whom 376 had any incident tooth loss (due to periodontal disease, caries, or both), and 96 had no incident tooth loss due to any reasons.

[‡] Multivariable model: adjusted for age, annual family income, smoking status, frequency of dental visits, waist circumference and recreational physical activity.

[§] There are 144 women in this analysis, of whom 48 had incident tooth loss due to periodontal disease (with or without incident tooth loss due to caries), and 96 had no incident tooth loss due to any reasons.

[‖] There are 424 women in this analysis, of whom 328 had incident tooth loss due to caries and no incident tooth loss due to periodontal disease, and 96 had no incident tooth loss due to any reasons.

[¶] There are 470 women in this analysis, of whom 375 had any incident tooth loss (due to periodontal disease, caries, or both), and 95 had no incident tooth loss due to any reasons.

[#] There are 143 women in this analysis, of whom 48 had incident tooth loss due to periodontal disease (with or without incident tooth loss due to caries), and 95 had no incident tooth loss due to any reasons.

[**] There are 422 women in this analysis, of whom 327 had incident tooth loss due to caries and no incident tooth loss due to periodontal disease, and 95 had no incident tooth loss due to any reasons.