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Use of water 'softening and conditioning systems' significantly increases the risk of periodontitis: smoking considerations

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Background: The role of water in the etiology of periodontal disease is poorly understood.

Objectives: The objective of this study was to examine the association amongst water softness, risk for periodontitis, and smoking status.

Methods: We examined the association between use of water 'softening and conditioning systems' and the risk for periodontal disease in smokers and nonsmokers, using adult participants (18 + years), from the third National Health and Nutrition Examination Survey (NHANES III) data. Zero to 33 per cent (0–33%) of sites with periodontal attachment loss ≥ 3 mm was considered a healthy periodontium, and > 33% of sites with periodontal attachment loss ≥ 3 mm was defined as periodontitis. Soft water users were divided into 'yes' or 'no' using the question, 'Does your home have a "softening or conditioning system?".' Smoking subjects were divided into groups as follows: current smokers (had smoked ≥ 100 cigarettes in their lifetime, not currently smoking), or never smokers (had not smoked ≥ 100 cigarettes in their lifetime). Data was analyzed by univariate analyses using SPSS[®]. The 5% level of statistical significance was adopted throughout.

Results: Subjects that answered the question 'yes' to soft water use had a significantly higher risk of periodontitis (p < 0.05), adjusting for confounders. When mineral intake from foods was added to the model, the significance of periodontitis risk remained the same for the non-smoking, soft water-using subjects, whereas for the smoking, soft water-using subjects the risk for periodontitis increased significantly (p < 0.05) in most cases.

Conclusions: Thus, use of water 'softening and conditioning systems' significantly increased the risk for periodontitis, and smoking increased this risk.

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'Soft water' is a relative term; however, for water to be soft it must contain low amounts of dissolved calcium and magnesium (0-60 mg/l or 0-3.5 grains/)

gallon) (1). Epidemiological and clinical studies suggest that water supplies contain certain minerals that may either have potential health benefits (2–6) or harmful effects (2, 7, 8). Water softness has been associated with numerous adult diseases (9). Many investigators continue to refer to the hazard of residing in soft water areas as related specifically to cardiovascular diseases and mortality (10); however, support for this view has been progressively weakened. Jeppesen (11) reported a low incidence of ischemic heart death in Greenland (a soft water area). A negative association has been shown between water hardness and ischemic heart disease, and was said to be due to calcium (12). A recent study reported that drinking tap water increases blood pressure (8), but could not determine if the effect was from the water itself or from chemicals or electrolytes in the water (13).

Diseases associated with water softness (e.g. cardiovascular pathology and mortality, hypertension, and osteoporosis) have also been associated with periodontal disease (14–17). Also, a strong association between cigarette smoking and periodontitis has been established (18). Although soft water consumption has been extensively studied in relation to cardiovascular disease, these authors are unaware of studies that have examined the association amongst water softness, risk for periodontitis, and smoking status.

Material and methods

Data for this study was obtained from the third National Health and Nutrition Examination Survey (NHANES III), conducted from 1988 to 1994, which was designed to provide estimates of the health status of the United States' civilian, non-institutionalized population aged 2 months and over (19). For this analysis, three public-use data files - household adult (20), examination (21), and laboratory (22), were obtained in CD-ROM and merged into one data file. This study was limited to individuals 18 years of age and older. Of the 17,821 subjects aged ≥ 18 years who received a clinical health examination in NHANES III, 13,652 (91.9%) received a periodontal examination. Reasons for data exclusion have been discussed elsewhere (18). The independent variable of interest was the percentage of periodontal sites per subject with attachment loss of ≥ 3 mm. Periodontal examinations were conducted in the mobile examination centers by six calibrated dentists trained in the use of epidemiological indices for oral health and are described elsewhere (15). For this study, extent scores (23), representing the percentage of sites per subject with attachment loss of 3 mm or greater, were calculated and categorized into two groups.

Zero to 33 per cent (0–33%) of sites with periodontal attachment loss of \geq 3 mm was considered normal, and >33% of sites with periodontal attachment loss \geq 3 mm was defined as periodontitis. The threshold of 3 mm was used to increase the likelihood that attachment loss was the result of disease and not measurement error. This grouping was consistent with other studies reporting NHANES III data (15). The analysis excluded persons who were edentulous.

From their responses to several questions administered in the household interview, participants in NHA-NES III were classified as: (i) either 'soft water' users (answered 'yes' to 'Does your home have a water softening or conditioning system?') or not 'soft water' users (answered 'no' to 'Does your home have a water softening or conditioning system?'); and (ii) current smokers (had smoked ≥ 100 cigarettes in their lifetime and currently smoked), former smokers (had smoked ≥100 cigarettes in their lifetime, not currently smoking), or never smokers (had not smoked ≥ 100 cigarettes in their lifetime). Current smokers were asked how many packs of cigarettes they smoked per day and number of cigarettes they smoked per day when they smoked the most; and former smokers were asked the age at which they last smoked cigarettes fairly regularly and the number of packs of cigarettes per day they smoked when they smoked the most. The number of years since quitting was calculated by subtracting age as reported from age at interview. Reasons for using selfreported measures of smoking only have been discussed elsewhere (18). Data was analyzed using SPSS® version 10.1 (SPSS Inc., Chicago, IL, USA). Group comparisons were made using univariate logistic regression to calculate crude odds ratios. Established risk factors for periodontal disease were selected covariates. The continuous covariates were age (years), body mass index, waist circumference to hip circumference, socio-economic status [poverty income ratio (unimputed income)], education level (years), drinking water intake (converted from ounces/day to g/day) and water intake from foods and beverages (g/day). The categorized (coded) covariates were race (Caucasian = 1, African



Fig. 1. The distribution of 'soft water' users (% yes) in the third National Health and Nutrition Examination Survey (NHANES III) sampling, separated by geographical location, and urban and rural areas. *p < 0.05, significantly different when compared to the urban area in the Midwest.

American = 2, and other = 3), gender (male = 1 and female = 2), a selfreported history of diabetes (selfreported by 'Has the doctor ever told you that you have diabetes?': yes = 1and no = 0), and physical activity ('In the past month did you jog or run?": yes = 1 and no = 0). Additional covariates were geographic location [Northeast = 1, Midwest = 2, South =3 (weighting in Texas), and West = 4], along with 'Urban' (> 1 million population: code = 1) and 'Rural' (all other areas: code = 2), and 'Is your water supply from a public or private well/cistern' (coded: yes = 0, no = 1). Furthermore, in order to determine if this effect was due to exogenous elements derived from food consumption, we added calcium, phosphorus, magnesium, sodium, copper, iron, and zinc intake, and urinary cadmium, as continuous covariates to our model. The administration of food-frequency questionnaires and a detailed 24 h dietary recall was used to record food consumption (24). Reasons for the use and inclusion of demographic information, and the administration of food-frequency questionnaires and a detailed 24-h recall have been described in the literature (25). Urinary cadmium was included as a covariate, due to the high levels of urinary cadmium in cigarette smokers (two times higher than non-smokers) (26). The 5% level of statistical significance was adopted throughout.

Of the 13,652 adult subjects who received periodontal examinations, two were missing data on smoking; 47 did not have data on cigarettes smoked per day (current smokers) or number of years since quitting (former smokers). An additional 5794 respondents were missing data on one or more covariates (primarily 'Does your home have a water softening or conditioning system?'). We limited the detailed analysis in this study to the 7858 subjects with complete data (57.6% of those who received a periodontal examination).

Results

The distribution of soft water users in the NHANES III sampling is shown in

Table 1. Population characteristics, risk factors for periodontal disease, water use, and total mineral intake in periodontitis^a subjects versus individuals with no periodontitis

Population characteristics	No pariodontal disassa	Yes
Population characteristics	periodontal disease	periodontal disease
Age, years	47.4 (0.2)	45.9 (0.6)*
Male, %	46.7	62.3*
Education level, years	10.84 (0.04)	10.66 (0.11)
Poverty index	235.0 (2.1)	245.7 (5.5)
Caucasian, % total	68.9	65.4
African American, % total	28.1	31.8
Other, % total	3.0	2.9
Risk factors		
Diabetes history, % yes	8.1	7.1
Body mass index	26.38 (0.05)	27.25 (0.12)†
Waist to hip ratio	0.889 (0.001)	0.964 (0.002)†
Jog or run, % yes	12.2	12.2
Smoking history		
Current smoker, % yes	48.2	51.5
Packs/day	1.01 (0.16)	1.23 (0.09)
# cigarettes/day when smoked most	26.9 (0.7)	27.3 (1.8)
Quitter, % yes	75.4	74.7
Number of years quit	24.7 (6.0)	17.8 (14.0)
Number of packs/year before quitting	0.69 (0.05)	1.34 (0.20)
Never smoked, % yes	50.8	49.9
Mineral intake from food and beverages		
Calcium intake (mg/day)	807.8 (4.8)	785.4 (11.2)
Phosphorus (mg/day)	1172 (6)	1142 (14)
Magnesium intake (mg/day)	252.5 (1.3)	245.4 (3.1)*
Sodium intake (mg/day)	3016 (17)	2962 (43)
Copper intake (mg/day)	1.16 (0.01)	1.12 (0.02)
Iron intake (mg/day)	15.1 (0.1)	13.8 (0.2)†
Zinc intake (mg/day)	11.9 (0.1)	10.8 (0.2)†
Urinary cadmium (ng/ml)	0.59 (0.01)	0.60 (0.02)
Water consumption		
Drinking water (g/day)	1015.0 (9.9)	933.7 (22.7)‡
Total water (g/day)	1831.4 (9.0)	1806.7 (23.6)
Water type and location, % total		
No water softening system	90.5 (6123)	88.6 (971)
Yes water softening system	9.5 (640)	11.4 (125)*
Public or private water company	89.2 (6178)	88.7 (1010)
Public or private well/cistern	10.8 (749)	11.3 (129)
Urban	86.1 (4011)	13.9 (650)
Rural	85.9 (4004)	14.1 (657)
Northeast	87.2 (1187)	12.8 (175)
Midwest	86.4 (1551)	13.6 (244)
South (weighting in Texas)	85.8 (3412)	14.2 (563)
West	85.2 (1865)	14.8 (325)

^a > 33% of sites with periodontal attachment loss \ge 3 mm.

*p < 0.05, †p < 0.01, ‡p < 0.005. Significantly different when compared with subjects with no periodontal disease.

Fig. 1. The percentage of soft water users was similar in the North-east in both urban (6%) and rural (6%) areas, in the South (weighting in Texas) urban (6%) and rural (7%), and in the West urban (13%) and rural (11%), whereas in the Midwest the percentage of soft water users was significantly higher in rural areas (25%) when compared to urban areas (7%) (p < 0.05). Population characteristics for subjects with and without periodontitis are shown in Table 1. Subjects with periodontitis had risk factors including demographics, medical conditions, smoking, drinking water intake, and mineral intake from foods and beverages. When compared with healthy subjects, periodontitis subjects were significantly younger and male (p < 0.05), had significantly higher

Table 2. Population characteristics, risk factors for periodontal disease, water use, and total mineral intake in subjects whose homes have 'soft water and conditioning systems' versus those homes that do not have 'soft water and conditioning systems'

Population characteristics	Answered 'no' to soft water system	Answered 'yes' to soft water system 47.2 (0.5)	
Age, years	47.6 (0.2)		
Male, %	48.2	48.7	
Education level, years	10.74 (0.03)	11.71 (0.09)§	
Poverty index	239.3 (1.5)	235.8 (4.5)	
Caucasian, % total	69.2	67.5	
African American, % total	27.7	29.5	
Other, % total	3.0	3.0	
Risk factors			
Diabetes history, % yes	8.1	8.1	
Body mass index	23.56 (0.06)	23.52 (0.17)	
Waist to hip ratio	0.908 (0.001)	0.910 (0.002)	
Jog or run, % yes	11.5	12.0	
Smoking history			
Current smoker, % yes	48.8	50.1	
Packs/day	1.25 (0.06)	1.05 (0.16)	
# cigarettes/day when smoked most	23.5 (1.1)	25.7 (4.4)	
Quitter, % yes	75.5	76.0	
Number of years quit	12.4 (2.9)	15.4 (11.5)	
Number of packs/year before quitting	1.14 (0.12)	1.11 (0.34)	
Never smoked, % yes	49.7	53.2	
Mineral intake from food and beverages			
Calcium intake (mg/day)	816.4 (4.4)	819.5 (14.0)	
Phosphorus (mg/day)	1169 (5)	1185 (17)	
Magnesium intake (mg/day)	250.6 (1.2)	251.4 (3.6)	
Sodium intake (mg/day)	2950 (10)	3011 (48)	
Copper intake (mg/day)	1.15 (0.01)	1.16 (0.02)	
Iron intake (mg/day)	13.8 (0.1)	13.9 (0.2)	
Zinc intake (mg/day)	10.2 (0.1)	10.3 (0.2)	
Urinary cadmium (ng/ml)	0.60 (0.01)	0.61 (0.02)	
Water consumption			
Drinking water (g/day)	973.9 (8.5)	960.2 (27.7)	
Total water, food and beverages (g/day)	1543.3 (7.5)	1542.0 (23.2)	
Water type and location, % total			
Public or private water company	89.4 (13,601)	78.0 (1254)	
Public or private well/cistern	10.6 (1607)	22.0 (354)*	
Urban	91.5 (7304)	8.5 (677)	
Rural	89.6 (8032)	10.4 (935)	
Northeast	93.9 (2336)	6.1 (153)	
Midwest	84.5 (3486)	15.5 (541)	
South (weighting in Texas)	93.5 (7071)	6.5 (492)	
West	87.5 (2984)	12.5 (426)	

*p < 0.05, $\dagger p < 0.01$, $\ddagger p < 0.005$, \$ p < 0.001. Significantly different when compared with subjects with 'no' water softening system.

body mass index and waist to hip ratio (p < 0.001), consumed significantly more drinking water (p < 0.005), had significantly more home 'water softening or conditioning systems' (p < 0.05), and consumed significantly less dietary iron and zinc (p < 0.005) and magnesium (p < 0.05).

Population characteristics for subjects that answered 'yes' for a soft water conditioning system in their home are shown in Table 2. Users of water 'softening or conditioning systems' in their homes had a significantly higher education level (p < 0.001), and a significantly higher percentage of their water supplied from a public or private well/cistern (p < 0.05) when compared with individuals that answered 'no' for a water 'softening or conditioning system' in their home.

Home water 'softening or conditioning system' use was associated with an increased risk of periodontitis

(Table 3). The odds ratios for perioincreased dontitis significantly (p < 0.05) for the following groups of subjects sampled: (i) home water conditioning 'softening or systems' users who were not current smokers and had never smoked and (ii) current smokers in both the unadjusted model and the model adjusted for demographic, medical, and lifestyle, when compared to the not currently smoking and never smoked 'no' users of water 'softening or conditioning systems'. After further adjustment for mineral intake from foods, such as calcium, magnesium, copper, iron, zinc, and sodium intake, and urinary cadmium levels, risk for periodontitis were significantly higher for: current and former smokers 'yes' soft water using subjects (p < 0.05) when compared to the never smoked 'no' soft water using subjects; and the current smoker groups that used water 'softening or conditioning systems', when compared to the never smoked and former smoker groups, respectively. Diagnostic testing for collinearity was performed. The results indicated that collinearity of the covariates used were inconsequential in the overall outcome of the initial and final models.

Discussion

This study suggests that use of 'soft' water significantly increased the risk of periodontitis. Minerals found in water have been studied in terms of both harmful and beneficial effects (27). From an epidemiological point of view we were mainly interested to see whether 'soft' water would modify the risk of periodontitis, possibly by mechanisms relating to low levels of magnesium and calcium in this water (10). 'Hard' water (which has been reported to contain higher levels calcium and magnesium than soft water) use has previously been reported to be inversely related to various health problems (28) as well as mortality (29). Relationships between periodontitis and calcium (30-32) and magnesium (33) intake have been reported, as well as the relationship between osteoporosis and periodontitis (17), and dietary

Table 3. Prevalence and odds ratios of periodontitis^a among dentate persons aged 18 years or older, by use of water 'softening and conditioning systems' and cigarette smoking status – United States, 1988–1994, the third National Health and Nutrition Examination Survey (NHANES III)

Home 'soft water or conditioning system'	Smoking status	Prevalence of periodontitis %	Unadjusted Odds ratio (95% CI)	Adjusted Odds ratio ^b (95% CI)	Adjusted Odds ratio ^c (95% CI)
No	Never smoked	13.8	1.00 (reference)	1.00 (reference)	1.00 (reference)
No	Current and former smokers	13.6	1.02 (0.89–1.17)	1.06 (0.91–1.23)	1.03 (0.86–1.23)
Yes	Never smoked	16.3	1.25 (0.94-1.65)	1.26 (0.93-1.71)	1.29 (0.89–1.86)
Yes	Current and former smokers	16.4	1.24 (0.93–1.66)	1.28 (0.92–1.77)	1.50 (1.02–2.21)*
No	Not current smokers and never smoked	13.1	1.00 (reference)	1.00 (reference)	1.00 (reference)
No	Current smokers	14.3	1.05 (0.85-1.30)	1.05 (0.85-1.30)	0.96 (0.74-1.24)
Yes	Not current smokers and never smoked	19.9	1.57 (1.03–2.39)*	1.57 (1.03–2.39)*	1.50 (0.90-2.50)
Yes	Current smokers	19.9	1.63 (1.07-2.50)*	1.63 (1.07-2.50)*	1.62 (0.96-2.73)
No	Former smoker	14.5	1.00 (reference)	1.00 (reference)	1.00 (reference)
No	Current smoker	15.0	1.04 (0.77-1.42)	1.10 (0.77-1.56)	1.24 (0.80-1.93)
Yes	Former smoker	20.0	1.48 (0.93-2.35)	1.59 (0.69-3.66)	1.40 (0.45-4.36)
Yes	Current smoker	20.0	1.48 (0.70–1.42)	1.66 (0.96–2.88)	2.13 (1.08-4.22)*

^a > 33% of sites with periodontal attachment loss \ge 3 mm.

^bAdjusted for age, race, gender, body mass index, waist to hip ratio, diabetes history, socioeconomic status, education level, and physical activity.

^cAdjusted for age, race, gender, body mass index, waist to hip ratio, diabetes history, socioeconomic status, education level, physical activity, drinking water intake, water intake from foods and beverages, water source, geographic location (i.e. urban vs. rural; and Northeast, Midwest, South, and West), calcium, phosphorus, magnesium, copper, iron, zinc, and sodium intake; and urinary cadmium levels. *p < 0.05.

CI, confidence interval.

calcium deficiency has been shown to cause decreased bone mineral density of alveolar bone in rats (34). Recent data also indicate that adverse health effects of cadmium exposure, including low bone mineral density and fractures (35), may occur at lower exposure levels than previously anticipated (36). Although water tends to have low levels of cadmium, cigarette smoking is a major source of cadmium exposure (37), whereas in non-smokers, food is the most important source of cadmium exposure (38).

Several limitations of our study should be considered in interpreting our findings. These are: (i) whether the use of 'water softening or conditioning systems' in the home preceded the onset of periodontal disease; (ii) whether smoking preceded the onset of periodontal disease; (iii) lack of differentiation between active periodontal disease and long-standing periodontal attachment loss; (iv) length of time subjects used 'water softening and conditioning systems' in their homes; (v) mineral content of 'soft water' as compared to 'hard water' in the United States; (vi) the underestimation of periodontal disease due to reasons that have been discussed previously (18); and (vii) the inability to control for the microbial composition of water and dental plaque.

Our results suggest that 'soft water or conditioning system' use in the home significantly increased the risk of periodontal disease, and current smoking increased this risk, even when mineral intake from foods and beverages, and urinary cadmium was added to our model. The exact mechanism whereby 'soft' water use acts directly or by interaction of the elements contained therein in the pathogenesis of periodontitis may be due to low calcium and magnesium levels in soft water; however, this has not yet been proven. Further studies are needed.

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