Root Proximity as a Risk Factor for Progression of Alveolar Bone Loss: The Veterans Affairs Dental Longitudinal Study

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Background: The purpose of the present longitudinal study was to evaluate the association between root proximity and the risk for alveolar bone loss (ABL).

Methods: We used data from the Veterans Affairs Dental Longitudinal Study, a closed-panel longitudinal cohort study of 1,231 men enrolled in 1968 with triennial follow-up examinations. Periapical radiographs of mandibular incisors from subjects with ≥10 years of follow-up were selected. Interradicular distance (IRD) at the cemento-enamel junction and alveolar bone levels at baseline and last follow-up were measured using digitized radiographs. The rate of progressive ABL was determined and expressed as millimeters per 10 years. Site-specific multivariate regression models were fit to evaluate the association between IRD and ABL rate, adjusting for age and smoking. Empirical standard errors and generalized estimating equations were used to account for the correlation among sites within subjects.

Results: There were 473 dentate subjects, aged 28 to 71 years at baseline, with ≥10 years of follow-up data available for analyses. The mean follow-up time was 23 years. The mean IRD was 1.0 ± 0.3 mm, and the mean ABL rate during 10 years was 0.61 ± 0.59 mm. There was a significant non-linear association between IRD and ABL rate (P <0.005). Compared to sites with IRD ≥0.8 mm, sites with IRD <0.6 mm were 28% (95% confidence interval [CI]: 11% to 48%) more likely to lose ≥0.5 mm of bone during 10 years (relative risk: 1.28 [95% CI: 1.11 to 1.48]) and 56% (95% CI: 11% to 117%) more likely to lose ≥1.0 mm of bone during 10 years (relative risk: 1.56 [95% CI: 1.11 to 2.17]).

Conclusions: IRD <0.8 mm is a significant local risk factor for alveolar bone loss in mandibular anterior teeth. Measurement of IRD may have important prognostic value in making treatment decisions. *J Periodontol 2008;79:654-659.*

KEY WORDS

Alveolar bone loss; periodontal disease; periodontitis; risk factor.

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The concept of "root proximity" was introduced by Trossello and Gianelly[1] to describe the clinical condition in which insufficient distance, defined as ≤1.0 mm, exists between the roots of adjacent teeth to maintain periodontal health. A human histologic study[2] showed that the quality and quantity of the interproximal septa are determined, in part, by interradicular distance (IRD). When IRD was >0.5 mm, the cancellous bone was flanked by lamina dura, whereas when it was <0.5 but >0.3 mm, the roots were separated by a fused lamina dura with no cancellous bone. It also was shown that when IRD was <0.3 mm, two juxtaposed roots were connected only by periodontal ligament without any bone tissue present between the roots.[2] However, there is a paucity of data regarding whether these histologic differences have relevance as local risk factors for progressive alveolar bone loss (ABL).

The mechanisms by which root proximity may impact periodontal health remain undetermined. Some clinical reports[3-8] recommended that dental health

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care providers give careful consideration to inadequate embrasure because root proximity may restrict plaque removal, limit access to instrumentation, lead to unfavorable papillae forms, and complicate the nature of a dental prosthesis. Other reports[7,9] argued that root proximity may be a local risk factor for periodontal breakdown because of its association with the quality and quantity of interproximal soft and hard tissue components. However, epidemiologic evidence of an association between the severity of root proximity and the initiation and/or progression of periodontal attachment loss or bone loss has been inconsistent.[1,5,10-12] Hence, it is not clear whether root proximity is a local risk factor for the initiation and/or the progression of periodontitis.

Although it has been argued that the dimension of the interproximal space may be an important factor in clinical periodontics, orthodontics, and prosthodontics, no universally accepted definition of root proximity exists. In other words, no accepted threshold of IRD has been defined clearly below which clinical problems or an increased likelihood of pathology can be expected. The limited number of studies or scholarly articles[1,5,10-12] that have investigated the possible effect of root proximity on periodontal health used a variety of operational definitions of root proximity. These inconsistencies relate to the exact location at which IRD is measured, as well as to the threshold(s) used to define or categorize root proximity. Although one study[11] used a continuous measure of IRD, other studies defined root proximity as IRD <1 mm[1,4] or <0.8 mm.[10] One recent report[13] proposed a three-level classification of root proximity: severity 1 = 0.5 to ≤0.8 mm; severity 2 = 0.3 to ≤0.5 mm; and severity 3 = ≤0.3 mm. To the best of our knowledge, no study has established the dose-response relationship between IRD and the risk for periodontitis that would provide a basis for a definition of root proximity based on its biologic effects. The lack of an accepted definition of root proximity makes comparisons between studies difficult and impedes the development of relevant diagnostic and/or therapeutic guidelines, which would be of particular relevance for orthodontics.

The objectives of this study were to evaluate the association between IRD and local progression of ABL in a longitudinal cohort study and to determine the dose-response function of this association.

MATERIALS AND METHODS

Study Sample

The study sample was selected from the Veterans Affairs (VA) Dental Longitudinal Study (DLS), the dental component of the VA Normative Aging Study (NAS). The NAS, initiated in 1963, is an ongoing closed-panel longitudinal cohort of community-dwelling men from the Greater Boston area who were systemically healthy at the NAS baseline.[14] Beginning in 1968, 1,231 NAS subjects volunteered to enroll in the DLS.[15] Research participants return approximately every 3 years for comprehensive medical and dental examinations and for interviews to assess behavioral factors, such as smoking. NAS and DLS subjects are not VA patients, and subjects receive their medical and dental care in the private sector.

The comprehensive dental examinations administered as part of the DLS included a periodontal examination and periapical radiographs. Radiographs of mandibular incisors from baseline and follow-up examinations were reviewed and digitized.** The study was limited to mandibular incisors because previous studies[10,13] reported the prevalence of root proximity to be highest in that region. Measurements were taken between mandibular left lateral and left central, left central and right central, and right central and right lateral incisors. The following site-specific inclusion criteria were established: ≥10 years of follow-up for interproximal space, presence of interproximal contact area without overlap of crowns, teeth without previous restorations, teeth with fully intact clinical crowns, and root completely visible and measurable. The following were exclusion criteria: open interproximal contact, undetectable cemento-enamel junction (CEJ), and severe incisal wear (>1/3). These inclusion/exclusion criteria were applied to each eligible interproximal space (maximum of three interproximal spaces per subject).

We identified 744 men who were dentate at DLS baseline and who attended at least one follow-up examination ≥10 years after baseline. Of these dentate men, 23 subjects did not have any anterior teeth present, and 248 subjects did not contribute any measurable interproximal spaces to our analysis because of various factors, including no incisor radiographs available in the record, incisor overlap, open contacts, rotation, and crowns/bridges masking the CEJ. In total, 1,069 interproximal spaces in 473 subjects met all of the inclusion and exclusion criteria.

Radiographic Measurements

All radiographic assessments and measurements were performed by one investigator (TK) in random order, i.e., baseline and follow-up radiographs were not paired to mask the investigator to whether specific radiographs were from baseline or follow-up. IRD was measured at the level of the CEJ from digitized radiographs using image analysis software†† at ×3 magnification. IRD was measured at the CEJs of two neighboring teeth that made up the boundaries of the interproximal site. Alveolar bone level was measured from the CEJ to the alveolar crest at the mesial

** HP Scan Jet 4570c, Hewlett-Packard, Palo Alto, CA.
†† Image J, National Institutes of Health, Bethesda, MD.

and distal aspects of the roots defining the interproximal space. Root length was measured as the distance from the CEJ to the root tip. Bone loss at both adjacent root surfaces was determined as the difference between alveolar bone levels from follow-up and baseline radiographs. The ratio of root length measures from baseline and follow-up radiographs was used to control for projection differences between baseline and follow-up radiographs by multiplying it by the bone loss measured on the follow-up radiograph. For each interproximal space, the maximum of the longitudinal bone loss measures of the two adjacent root surfaces was the primary outcome measure for this study. Results using the mean of the two values were very similar and are not reported here. The average annual rate of bone loss during follow-up was calculated by dividing the bone loss measure by the follow-up time in years. Ten percent (47 of 473) of the subjects' radiographs were selected randomly and measured a second time to determine the intraexaminer reliability.

Assessment of Other Variables

Subjects' smoking history was obtained by interviewer-administered questionnaires at baseline. For the purpose of the present analysis, men were classified as never-smokers, former smokers, or current smokers of cigarettes. At each follow-up cycle, the clinical examination assessed plaque ("none," "interproximal only," "interproximal with continuation on buccal or lingual," or "all surfaces with 2/3 of tooth") and calculus ("none," "discontinuous flecks," "noncontinuous band on parts of tooth," or "continuous band around tooth").[15] Methodologic details regarding the assessment of clinical periodontal variables and their reproducibility were published previously.[16,17] For each interproximal site, we calculated the mean plaque and calculus scores of the two adjacent teeth over all examination cycles. Furthermore, men with two or more teeth (other than third molars) with radiographic bone loss >20% were identified at baseline for descriptive purposes.

Statistical Methods

Descriptive statistics were calculated on a per-subject basis as mean, standard deviation, median, 25/75 percentiles, and minimum and maximum values. For site-specific analyses, the interproximal space was used as the unit of analysis. To evaluate the association between IRD and ABL rate, linear regression models were fit. The annual rate of ABL (in millimeters) was the dependent variable. IRD (in millimeters) was the primary exposure variable. To allow for nonlinearity in the modeling of the dose-response relationship, fractional polynomial regression in the form $\text{RateABL} = \beta_0 + \beta_1\ \text{IRD}^{0.5} + \beta_2\ \text{IRD} + \beta_3\ \text{IRD}^{1.5}$ was fit, where RateABL is the rate of bone loss (in millimeters). Robust standard errors were used to account for the clustering of interproximal spaces within subjects. A partial F test was used to evaluate the nonlinearity of the dose-response function. In addition, IRD was categorized based on cut-offs derived from the graphic analysis of the fractional polynomial regression model described above. Indicator variables were created based on categories of IRD and were used to model the association between IRD and the rate of bone loss in a linear regression model. Models were adjusted for age and smoking. To explore if impaired oral hygiene may be a mediator, i.e., in the causal pathway of root proximity and periodontitis risk, models also were adjusted for plaque, calculus, and gingivitis scores.

In addition, the rate of bone loss was dichotomized using thresholds of 0.5 and 1.0 mm per 10 years. Generalized linear models were used to calculate the relative risk (risk ratio) for bone loss >0.5 mm (versus ≤0.5 mm) and >1.0 mm (versus ≤1.0 mm) per 10 years, comparing different categories of IRD. The method of generalized estimating equations using an exchangeable working correlation matrix was used to account for the clustering of sites within subjects.

All statistical analyses were conducted using a software package.[‡‡]

RESULTS

The final analytic sample consisted of 1,069 interproximal spaces in 473 men. The mean age at baseline was 46 years (range: 28 to 71 years). Subjects were followed for a mean of 23 years (range: 10 to 35 years, Table 1). IRD varied from 0.3 to 2.4 mm (mean: 1.0 ± 0.3 mm). Additional baseline characteristics of the study sample are given in Table 1. The reproducibility of the radiographic measurements was excellent. For repeat measurements of radiographs of 47 randomly selected subjects, the intraclass correlation coefficients were 0.98 (95% confidence interval [CI]: 0.97 to 0.98) for the measurement of IRD and 0.94 (95% CI: 0.91 to 0.96) for the rate of ABL.

We found an inverse association between IRD and the rate of ABL ($P = 0.005$) and an indication of nonlinearity in the dose-response function based on fractional polynomial regression ($P = 0.09$) (Fig. 1). Compared to sites with IRDs ≥0.8 mm, sites with IRDs <0.6 mm were 28% (95% CI: 11% to 48%) more likely to lose ≥0.5 mm of bone (relative risk: 1.28 [95% CI: 1.11 to 1.48]) and 56% (95% CI: 11% to 117%) more likely to lose ≥1.0 mm of bone during 10 years (relative risk: 1.56 [95% CI: 1.11 to 2.17], Table 2).

On average, sites with IRD <0.6 mm had 0.22 mm more bone loss during 10 years compared to sites with

‡‡ Stata 7.0, STATA, College Station, TX.

Table 1.

Summary Statistics of Subject Characteristics at Baseline (N = 473)

Age (years; mean ± SD)	46 ± 7.4
Plaque index (mean ± SD)	1.3 ± 0.4
Calculus index (mean ± SD)	1.4 ± 0.5
Follow-up (years; mean ± SD)	23 ± 6.3
IRD (mm; mean ± SD)	1.0 ± 0.3
Baseline bone loss (mm; mean ± SD)	2.7 ± 1.1
Rate of bone loss (mm/10 years; mean ± SD)	0.61 ± 0.59
Smokers (n [%])	
Never	179 (38)
Former	150 (32)
Current	135 (29)
Subjects with ≥2 teeth with >20% ABL (n [%])	158 (33)

Numbers may not add up to 100% because of missing values.

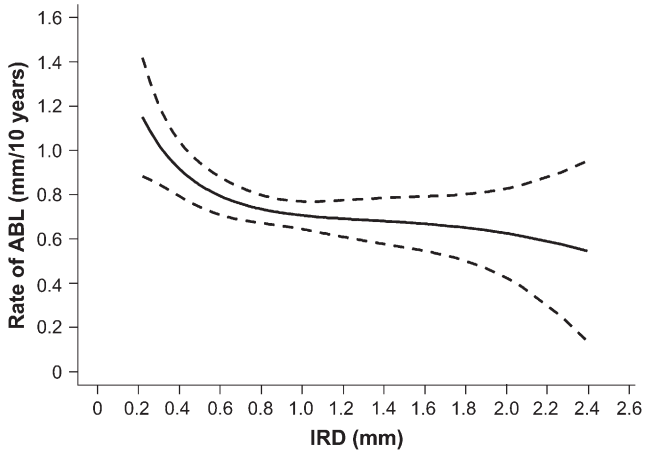

Figure 1.
Association between IRD and rate of ABL (fitted values and 95% confidence bands of fractional polynomial regression model).

Table 2.

Age-Adjusted Risk Ratio and 95% CI for ABL ≥0.5 mm and ≥1.0 mm During 10 Years for Different Categories of IRD

	Bone Loss ≥0.5 mm/10 Years		Bone Loss ≥1.0 mm/10 Years	
IRD (mm)	Risk Ratio	95% CI	Risk Ratio	95% CI
≥0.8	1	Reference	1	Reference
≥0.6 to <0.8	1.12	1.01 to 1.26	1.11	0.85 to 1.44
<0.6	1.28	1.11 to 1.48	1.56	1.11 to 2.17

IRD ≥0.8 mm. Adjustment for age and smoking did not attenuate the association between IRD and rate of bone loss (Table 3). Further adjustment for plaque and calculus did not result in an attenuated association (Table 3). Other statistically significant predictors of ABL in this model were smoking (former smoker versus never-smoker: β = 0.17 mm [95% CI: 0.05 to 0.28 mm] and current smoker versus never-smoker: β = 0.25 mm [95% CI: 0.12 to 0.38 mm]) and calculus (mean calculus score: β = 0.14 mm [95% CI: 0.01 to 0.26 mm]).

DISCUSSION

The present study demonstrated a dose-dependent, non-linear, inverse association between IRD and ABL. There was no clinically relevant association between IRDs of more than ~0.8 to 1.0 mm and ABL. However, IRDs <0.8 mm were associated with a moderately increased risk for loss of alveolar bone.

The CEJ is a reproducible and reliable landmark to measure IRD.[10,11] However, different methods of assessing root proximity, such as evaluating the distance between adjacent roots along the entire root surface, have been used. For example, in their clinical study, Heins et al.[11] defined root proximity as the mean of the IRD at the CEJ and the IRD at the most coronal alveolar crestal bone level. On average, this method yields greater IRDs; the distance at the level of the CEJ tends to be smaller than the IRD at the alveolar bone level because of tapered root anatomy. More importantly, this measurement of IRD is a function of ABL, impeding the evaluation of an association between IRD and bone loss.

Because our study used longitudinal data, we needed a stable landmark that could be identified reliably at different points in time and yield reproducible measurements. Furthermore, assessing IRD at the CEJ has the added advantage that the CEJ typically is easily identifiable on radiographs. However, the IRD measured at the CEJ does not necessarily correspond to the IRD at the level of the crestal alveolar bone. Therefore, the measures of IRD in this study do not correspond directly to the histologic findings of Heins and Wieder.[2] Nevertheless, the findings that the quality of interproximal bone is dependent on the IRD provide a biologic rationale for the association found in the present study.[2]

We observed a dose-response relationship between IRD and the rate of bone loss in which the severity of ABL increased with decreased IRDs <0.8 mm. In contrast, there was no association between ABL and IRDs >0.8 mm. Thus, we propose a clinically useful approach to assess the likely impact of root proximity by the use of the graph (Fig. 1). For example, IRD ≤0.8 mm, as measured at the level of the CEJ, is associated clearly with an accelerating rate of ABL. In this study,

Table 3.

β Coefficients (95% CI) for Linear Regression of ABL Rate on IRD (in mm)

IRD (mm)	n	β*	β†	β‡	β§
≥0.8	690	0 (Reference)	0 (Reference)	0 (Reference)	0 (Reference)
≥0.6 to <0.8	271	0.06 (–0.05 to 0.17)	0.06 (–0.05 to 0.17)	0.06 (–0.06 to 0.17)	0.06 (–0.06 to 0.17)
<0.6	108	0.22 (0.06 to 0.38)	0.22 (0.07 to 0.38)	0.23 (0.08 to 0.39)	0.24 (0.08 to 0.40)

β coefficients (95% CI) for other independent variables in model were: age (10-year increments) = 0.06 mm (–0.01 to 0.12 mm); former smoker versus never-smoker = 0.17 mm (0.05 to 0.28 mm); current smoker versus never-smoker = 0.25 mm (0.12 to 0.38 mm); mean plaque score = 0.12 mm (–0.03 to 0.29 mm); and mean calculus score = 0.14 mm (0.01 to 0.26 mm).
* Crude.
† Adjusted for age.
‡ Adjusted for age and smoking.
§ Adjusted for age, smoking, plaque, and calculus.

the magnitude of the effect of IRDs <0.6 mm on the risk for ABL was comparable to that of cigarette smoking (Table 3). Furthermore, root proximity is not a rare condition. The fact that 10% of the sites in this study exhibited such small IRDs and 35% of sites exhibited IRDs <0.8 mm indicated that root proximity may be an important local risk factor for ABL at the population level.

To confound the association between root proximity and ABL, a variable would have to affect IRD and ABL risk. We identified many variables that are associated with ABL, but we have no evidence that any are associated with IRD as well. For example, age theoretically could be associated with smaller IRDs because a mesial drift of the aging dentition has been described.[18] However, IRD is determined largely by the anatomy of adjacent teeth at the interproximal space; therefore, important confounding of IRD by any behavioral or other risk factor for periodontitis, such as smoking, is unlikely. The finding that the regression coefficients did not change appreciably when models were adjusted for age and smoking are consistent with this assumption.

Root proximity may affect the risk for periodontitis, as manifested by progressive ABL, by limiting access for personal oral hygiene or professional cleaning.[8] In the present study, we attempted to explore this as a possible pathway by adjusting the model for plaque and calculus indices. The calculus index was associated significantly and positively with ABL; however, adjustment for plaque and calculus did not attenuate the association between IRD and ABL. This indicates that impaired oral hygiene may not be an important factor explaining the effect of root proximity on bone loss. However, the calculus and plaque indices available were recorded only on a per-tooth basis, and such relatively crude measures of oral hygiene may be insensitive in identifying important differences in hygiene factors in the interdental space. Hence, our findings do not rule out that plaque and/or calculus may mediate, at least partially, the effect of root proximity on ABL.

Strengths of the study include the longitudinal, population-based design and long observation period, its large sample size, and the site-specific analysis. Furthermore, we used strict inclusion/exclusion criteria with respect to the quality of the radiographs and the projection and visibility of key anatomic landmarks to minimize bias due to measurement error, as documented by excellent reliability. The largest previous study[12] investigating the association between root proximity and ABL analyzed the data at the level of the patient. This is an important shortcoming because root proximity is hypothesized to be a local risk factor for ABL, whereas on a patient level, many more subject-level risk factors and local risk factors at other sites contribute to the variability in ABL. Another strength of this analysis was our ability to evaluate the dose-response function of the association between IRD and ABL without any a priori assumption on its form. As one would expect, the association was not linear because only narrow IRDs should present an increased risk for ABL. This approach also allowed us to propose a definition of root proximity that has immediate relevance for an important dental health outcome (ABL). Furthermore, subjects in this study were not recruited based on their periodontal status or IRD, minimizing the chance for selection bias.

This study analyzed retrospective data and has certain limitations. Data specifically on the plaque and calculus status of the interproximal space were not available, limiting our ability to explore the importance of oral hygiene more closely. Because the study originally was created with men only, the results may not be generalizable to women. However, previous clinical research did not observe any differences in IRD or its association with ABL between genders.[1,10,11] Nevertheless, men generally are at higher risk for losing alveolar bone, and it is possible that the

association between root proximity and ABL is different in females.[19]

This study was limited to mandibular incisors because of the higher prevalence of root proximity in this region reported in previous studies.[10,11] Furthermore, root proximity has particular relevance for mandibular incisors because interproximal reduction of mandibular incisors frequently is considered to alleviate crowding during orthodontic treatment.[20] However, there is no reason to believe that the observed association is in any way specific to mandibular incisors.

CONCLUSIONS

Root proximity is a significant local risk factor for ABL in mandibular anterior teeth. In the presence of IRDs ~0.8 mm or less, clinicians should expect greater risk for ABL with decreasing IRDs. Hence, root proximity is an additional local risk factor for ABL that should be considered in periodontal treatment planning. Furthermore, this finding is of particular relevance for orthodontic treatment guidelines because root proximity can be modified by orthodontic therapy.

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