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Anterior malalignment and the risk for poor oral health

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ANTERIOR MALALIGNMENT AND THE RISK FOR POOR ORAL HEALTH

by

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DEDICATION

To my parents,

Maha and Abdulsalam,

To my sisters and brothers, and

To all of my friends,

Without whom none of my success would be possible

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ABSTRACT

Little knowledge and contradictory results are available on the effectiveness of incisor malalignment as an indicator of poor oral health (e.g., dental caries, periodontal disease). This research project aimed to examine the relationship between incisor malalignment and two common diseases of poor oral health—periodontal disease and dental caries—and their cumulative outcome (i.e., tooth loss) in anterior teeth. Prospective and cross-sectional data from the Veterans Affair (VA) Dental Longitudinal Study were utilized in this research. Incisor malalignment traits were measured by determining the anterior tooth size–arch length discrepancy index (aTSALD) and Little's Irregularity Index (LII). Incisor malalignment indices were categorized by severity. We computed per arch adjusted estimates of the amount of change/events in anterior periodontal disease, tooth loss, and dental caries (i.e., coronal and root caries) by the level of the incisor malalignment traits. Pocket depth (PD), clinical attachment loss (CAL), and alveolar bone loss (ABL) were used as periodontal disease outcomes. Prospective data included information from 400 maxillary and 408 mandibular casts with a complete set of anterior sextants. In the upper anterior arch, crowding and spacing were significantly associated with an increased mean PD. Maxillary incisor irregularity involved a significantly increased mean CAL. In the anterior mandibular arch, incisor crowding and irregularity were significantly associated with increased PD, CAL, and ABL. Prospective data to test the association between all-cause tooth loss and incisor alignment traits included a sample size of 400 maxillary and 408 mandibular casts with a complete set of anterior sextants. Maxillary segments with spacing had a 401% significantly greater hazard (hazard ratio [HR]= 5.01, 95% confidence interval [CI] = 1.16-21.64) of all-cause tooth loss, compared to the ideal alignment (i.e., the reference group). Multiple cross-sectional data to test the association between anterior dental caries outcomes and malalignment traits included a sample size of 211 maxillary and mandibular casts with a complete set of anterior sextants. Compared to ideally aligned teeth, spacing in the maxillary segment significantly decreased the mean maxillary anterior CDFT by 0.93 teeth. Specific malalignment traits may be linked to certain poor oral health indicators.

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Introduction and literature review

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Oral health is an essential part of general health (U.S. Department of Health and Human Services 2014). Dental caries and periodontal disease are two of the most common oral health diseases globally (Petersen et al. 2005). The World Health Organization (WHO) reported that dental caries has a prevalence of nearly 100% in adults (World Health Organization 2014). In addition, periodontal disease is highly prevalent, affecting nearly 90% of the population worldwide (Pihlstrom et al. 2005). Dental caries and periodontal disease are different in etiology and outcome, although these two diseases are grouped into a distinct category as a sign of poor oral health (Tezal et al. 2013).

Dental caries is defined as “the localized destruction of susceptible dental hard tissues by acidic by-products from bacterial fermentation of dietary carbohydrates” (Selwitz et al. 2007). It is one of the most preventable diseases. However, challenges exist in dental caries prevention, specifically because there is a substantial susceptibility to dental caries throughout an individual’s life (U.S. Department of Health and Human Services 2014). Dental caries is a reversible disease in its initial stages. Despite that, it is the main source of oral pain and tooth loss (Tezal et al. 2013). The pathophysiology of caries encompasses a discrepancy in the biological balance between tooth elements and the dental biofilm (Scheie and Petersen 2004).

Periodontal disease is a bacterial infection affecting the tissue supporting the tooth, which includes the gum, periodontal ligament fibers, cementum, and alveolar process. The development of deep pockets, bone damage, tooth mobility, and ultimately tooth loss usually occur as periodontal disease advances. The probable pathogenesis of periodontitis is an immune-inflammatory mediated reaction stimulated by the presence of biofilm bacteria in the periodontal tissue. Inflammatory mediators and host cellular components induce the destructive damage to soft and hard periodontal tissue (Preshaw et al. 2004).

Dental caries and periodontal disease are multifactorial diseases; therefore, the assessment of their risk of occurrence is complex. Risk is defined as the likelihood that a harmful event will take place. Risk assessment is the method of arranging and investigating all available scientific evidence that is significant to the issue being examined. A risk factor is “an environmental, behavioral, or biological factor confirmed by temporal sequence in longitudinal studies.” Risk factors can be a part of the causal chain or, at minimum, expose the host to the causal chain. When disease occurs, eliminating the risk factors does not necessarily lead to a potential reversal of the acquired illness. As the association between exposure and outcome is investigated in cross-sectional studies, the use of the term “risk indicator” is suggested (Beck 1998; Rodricks 2006).

Risk factors should be well determined and clearly understood to effectively manage diseases (AlJehani 2014). Risk factors for dental caries can be classified as local or general. Age, sex, race, geographical location, and socioeconomic status are general risk factors for dental caries. Furthermore, local risk factors may include oral hygiene, number of medications used, and salivary factors (Hunter 1988). Risk factors for periodontitis are primarily sex, smoking, alcohol, diabetes, metabolic syndrome, osteoporosis, dietary calcium, vitamin D, stress, and genetic factors (Genco and Borgnakke 2013). One important and often unexamined mutual risk factor for dental caries and periodontal disease is malocclusion.

Malocclusion is a vague phrase of a confusing concept. It can be defined as any deviation of the teeth and jaw from the normal or ideal occlusion. Malocclusion encompasses numerous interrelated occlusal traits, which include overjet, overbite, open bite, crossbite and dental malalignment (i.e., dental crowding and irregularity). Such occlusal characteristics may reveal malformations in dentition, the jaw, or both. Dental crowding, particularly anterior dental crowding, denotes an inadequate arch space in relation to the tooth size, which results in malposition of the teeth in the jaws, whereas irregularity deals with the labiolingual displacement of teeth without the incorporation of space (Lombardi 1982).

Dental crowding is one of the most common dental abnormalities in present civilizations with a worldwide high prevalence of 40‑80 percent (Evensen and Øgaard 2007; Rose and Roblee 2009). Previous studies have attempted to investigate the hypothesis that malalignment of the teeth is a risk factor for dental caries and periodontal disease. Malalignment interrupts the contact points between teeth, leading to inadequate self-cleansing and causing increased plaque and food depositions and retention (Helm and Petersen 1989a; Helm and Petersen 1989b; Hafez et al. 2012). Hence, it is logical to assume that malalignment of the teeth can increase the probability of the development of dental caries and periodontal disease.

Previous studies have attempted to investigate malalignment as risk factors for dental caries and periodontal disease; however, their conclusions were frequently tenuous (Bollen 2008; Hafez et al. 2012). This discrepancy in the literature is primarily attributable to the lack of differentiation between dental crowding and irregularity, together with other factors, which include using invalid or unreliable instruments to account for such exposures, and the multifactorial nature of dental caries and periodontal disease as outcomes. Furthermore, the validation of potential risk factors such as dental crowding or tooth irregularity requires a longitudinal study or a multiple cross-sectional design with a large number of recruited participants who have completed a long follow-up period.

HYPOTHESIS

Three hypotheses will be tested in this dissertation: (1) incisor malalignment traits are associated with an increased rate of anterior periodontal disease outcomes (i.e., PD, CAL, ABL); (2) incisor malalignment traits are associated with an increased rate of anterior tooth loss; and (3) incisor malalignment traits are associated with increased rate of dental caries (i.e., coronal and root caries).

LITERATURE REVIEW

The definition, etiology, and prevalence of malalignment in the literature will be reviewed. The background and importance of existing investigations of the effect of malalignment on the risk of developing dental caries and periodontal disease will be also discussed in this section. A brief summary and the proposed research objectives will be presented.

Dental Malalignment

Dental crowding is the discrepancy in the proportion between the mesiodistal width of the teeth and the existing space offered by the alveolar bone (i.e., tooth size–arch length discrepancy index). By definition, it is a distorted tooth/tissue ratio or a dentoalveolar discrepancy (Sanin and Savara 1973). Dental crowding is a tooth-arch size discrepancy and a divergence caused by several factors. Irregularity on the other hand denotes the facial–lingual displacement between adjacent teeth at their contact points. The direction of skeletal growth, premature loss of primary teeth, tooth width and arch dimension, oral muscles, and inclination of incisors and molars may be etiological factors involved in the development and severity of dental crowding and misalignment (Björk 1963; Sanin and Savara 1973; Rönnerman and Thilander 1978; Howe et al. 1983; Perera 1987).

The Scope of the Problem

In the United States (U.S.), the prevalence of incisal irregularity was primarily presented in two papers that analyzed the third cycle of the National Health and Nutritional Examination Survey (NHANES III 1988–1994) (Brunelle et al. 1996; Proffit et al. 1998). NHANES III was administered in two parts by the U.S. Center for Disease Control and Prevention (CDC; Atlanta, GA, USA) from 1988 to 1994. It is a U.S.-based, cross-sectional, nationally representative data of noninstitutionalized people living in households. Participants completed a survey questionnaire, medical/dental examination, and several laboratory tests. Further thorough information on the study design and protocol was previously reported (U.S. National Center for Health Statistics 1994).

The first part of NHANES III (1988–1991) was investigated by Brunelle et al. (Brunelle et al. 1996) who found that 75% and 78% of the U.S. population experienced some degree of maxillary and mandibular crowding, respectively. Proffit et al. (Proffit et al. 1998) explored both parts of NHANES III and found that dental crowding occurred across all racial groups, with barely 35% of adults having normally (i.e., < 2 mm) aligned mandibular incisors. By using Little’s Irregularity Index (LII), Proffit found that 15% of the population experienced severe incisal misalignment that could subject them to social and functional impairment.

Diagnostic Evaluation of Incisor Malalignment

In 1975, Robert Little introduced the Little's Irregularity Index (LII) as an approach to evaluate irregularity, and alignment of teeth independent of the space available in the arch (Little 1975). The LII was first developed to assess relapse on the mandibular anterior teeth following orthodontic treatment; investigators later extended its use to estimate incisor irregularity in the anterior segments of the maxillary and mandibular arches (Vaden et al. 1997).

By description, the LII measures the horizontal linear distance between incisal anatomical contact points in a labiolingual manner, parallel to the occlusal plane, starting and ending at the mesial anatomic contact of canines (Figure 1.1). A severity scoring system in millimeters was established from a five-point measurement, called the LII score. An irregularity index of less than 3.5 mm is described as "mild" or "acceptable", whereas an index in excess of 6 mm is regarded as "clinically severe" (Little 1975).

The tooth size–arch length discrepancy (TSALD) is a well-defined approach of measuring dental crowding (Warren et al. 2003). Along-side cephalometric and profile analysis, the TSALD or space analysis originally had an essential part in orthodontic practice as a diagnostic tool used to decide the need for extraction to accommodate teeth in the dental arches (Correia et al. 2014). The TSALD is the difference between the space available, indicated by the alveolar bone, and the sum of the mesiodistal width of the existing teeth (Sinclair and Little 1983). By design, it is capable of measuring the complete dentition (tTSALD) or it is limited specifically to measuring the anterior teeth (aTSALD) (Buschang and Shulman 2003) (Figure 1.2). Little's Irregularity Index and the TSALD are two distinct methods of assessing incisal irregularity and dental crowding. In fact, the TSALD more precisely measures crowding, compared to LII. This is primarily attributable to the fact that TSALD evaluates the displacement of teeth through subtracting the space available from the space required, whereas LII evaluates the labiolingual displacement of teeth via measuring the horizontal labiolingual shift between contact points independent of the space available (Staley and Reske 2010).

Several studies have investigated whether these indices are correlated with each other. The LII and TSALD were correlated in a statistically significant manner, but with a slight differences in clinical importance ($r = +0.53$; $r = -0.68$) (Alexander 1996; Björk and Skieller 1972). Therefore, it is important to distinguish between the terms “dental crowding” and “irregularity,” as measured by the appropriate indices described previously.

Other Malalignment Indices

In the current literature, there is an essential need to differentiate between indices that measure dental crowding and irregularity in relation to caries or periodontal disease. This factor is particularly important because dental crowding and irregularity involve different aspects of malocclusion. In this review, we provide separate accountability for such differences, based on the evidence that dental crowding involves displacement or rotation caused by a lack of space, whereas irregularity measures labiolingual displacement of the teeth without the consideration of the space factor (Staley and Reske 2010). Table 1.1 presents the indices and methods used to measure dental crowding or irregularity relative to dental caries and periodontal disease in the current literature.

The Change in Incisor Malalignment in Adult and Late-Adult Life

The dental arches experience some changes throughout an individual's lifetime (Carter and McNamara Jr. 1998). Few studies have attempted to investigate incisor alignment longitudinal changes during adult or late-adult life. In a longitudinal study, Carter and McNamara (Carter and McNamara Jr. 1998) investigated age-related incisor irregularity changes between the early fourth and mid-fifth decades in 10 individuals (5 men and 5 women). They found a significant increase in mandibular irregularity within the same individuals at both ages (mean difference ± standard deviation [SD], +0.48 ± 0.59 mm; $P < 0.05$). These results were statistically significant; however, they hold minimal clinical significance. In the same study, the authors reported that no statistically significant changes occurred in the maxillary incisors at the early fourth and mid-fifth decades (mean difference= +0.66 mm ±0.94 mm; $P > 0.05$). In a similar study, Dager et al. (Dager et al. 2008) examined the longitudinal changes in incisor irregularity between the late-fifth and late-sixth decades in 40 individuals (20 men and 20 women). They noted no significant change in incisor irregularity in neither the maxilla nor the mandible (maxilla: mean difference, 0.0 ± 1.1 mm; $P > 0.05$; mandible: mean difference, 0.4 ± 2.2 mm; $P > 0.05$).

To our knowledge, no study has attempted to investigate the longitudinal changes in incisor crowding in adulthood. However, it is important to note that Bishara et al. (Bishara et al. 1994) examined the age-related longitudinal change in dental crowding of the upper and lower anterior teeth using 30 participants (15 male and 15 female individuals) from the mid-second decade (approximately 15 years old; childhood) to the mid-fourth decade. The only significant finding was in the female participants who had a significant increase in lower incisor crowding when comparing measurements at the mid-second and mid-fourth decades (mean, -0.57 mm ±

0.77; $P = 0.01$). Several of these studies clearly carried conflicting results that can be attributed to significant sampling limitations (Bishara et al. 1994; Carter and McNamara Jr. 1998). The first limitation concerns the use of convenient samples in both studies. Such limitation restricts the generalizability of the results because it is difficult to estimate the degree of selection bias in the sample. A second limitation is the use of small sample sizes and no reported sample size calculation, which makes the power of these studies questionable. In the light of the aforementioned limitations, there is truly a need for longitudinal studies that will overcome these limitations and provide the current literature with valid results.

Time-related Alignment Change in Older Men

Because of these limitations and in an attempt to verify the assumption (i.e., evidence-based assumption) of no to minimal (i.e., <1 mm) time-related change in incisor alignment in our main data source, we used the Dental Longitudinal Study (DLS) data (Kapur et al. 1972) to investigate the hypothesis that time-related alignment change during 9–10 years (i.e., a decade) occurs in the incisor area during late adulthood. The DLS data are provided by a closed-panel prospective longitudinal study of aging and oral health that included 1,231 non-Hispanic white men, recruited from a parallel normative aging study from the U.S Department of Veteran Affairs, who did not receive their medical or dental treatment in the Veteran Affairs healthcare system (Bell et al. 1966). The participants received a comprehensive medical and dental examination every 3–4 years from 1968 to 2009, with a total of 13 triennial examinations. As part of the dental examination, upper and lower casts from alginate impressions were only obtained in the first five triennial examinations(1968–1985). For the current investigation, the inclusion criteria were participants who had measurable casts available, had not lost any anterior teeth after 9–10 years (i.e., a decade) of baseline cast records, did not have extensive restorative procedures that would have changed their arch parameter, and did not report past orthodontic treatment.

The sample size calculation was based on the method used in two similar studies (Bishara et al. 1994; Carter and McNamara Jr. 1998) and performed with the usage of power analysis for the paired sample t-test using SAS 9.4 (Moore et al. 2007). The average change in alignment in the DLS data was predicted to be consistent with the average recorded alignment change in the two similar studies (Bishara et al. 1994; Carter and McNamara Jr. 1998), based on 90% power, 5% level of significance, and 95% confidence level. To identify significant changes in the data, a paired t-test statistics using SAS 9.4 was conducted with an a priori of less than 0.05.

Thirty-nine adults with available upper and lower casts were included in the analysis, aged 36–67 years (mean age ± SD, 51 ± 7.6 years). In the upper and lower arches, incisor alignment was measured in accordance with two definitions: anterior tooth size–arch length discrepancy (aTSALD) (Harris et al. 1987), and Little's Irregularity Index (LII) (Little 1975). The aTSALD was obtained by subtracting the "space available" from the "space required," with negative values indicating crowding, positive values indicating spacing, and a zero value representing the ideal alignment. "Space available" was acquired in millimeters by applying a pliable ruler on the incisor edges from the distal contact point of the right canine to the distal contact point of the left canine (i.e., arch best fit). "Space required" was obtained through the sum of the maximum mesiodistal width in millimeters by using a digital electronic caliper. In individuals in whom the anterior teeth had dissimilar labiolingual position, the arch best fit was identified following most teeth curve. Furthermore, LII was obtained using a digital electronic caliper placed parallel to the occlusal plan that measured the labiolingual linear displacement of anatomical contact points from canine to canine in each anterior arch.

The observed time-related changes in incisor alignment in the upper and lower arches are summarized in Table 1.2. In this patient population, on average, we found that the maxillary anterior alignment increased towards crowding from 0.82 ± 1.51 mm to 0.78 ± 1.53 mm ($P = 0.05$), whereas mandibular anterior alignment decreased away from crowding from -0.49 ± 2.13 mm to -0.45 ± 2.05 mm ($P = 0.20$). Furthermore, on average, we found that maxillary anterior irregularity decreased from 3.25 ± 2.08 mm to 3.22 ± 2.0 mm ($P = 0.57$), and that mandibular anterior irregularity similarly decreased from 3.76 ± 2.09 mm to 3.75 ± 2.10 mm ($P = 0.80$). All recorded incisor alignment and irregularity changes in the upper or lower arch were neither statistically nor clinically significant.

We also stratified the results, based on the actual presence of incisor crowding (i.e., aTSALD alignment score of less than 0 mm) (Table 1.3). None of these observed changes were statistically significant. Therefore, we can confidentially assume no significant longitudinal changes occurred in the upper and lower incisor alignment and irregularity status in the DLS data.

Intra-rater Reliability of Crowding and Irregularity Measurements in the Dental Longitudinal Study

Alginate impressions and poured plaster upper and lower casts were collected as part of the first five triennial DLS dental examination data (1968–1985). The highest number of collected data was obtained in the second triennial examination. This examination, rather than the first triennial examination, was consequently set as the baseline. A total of 476 participants with upper and lower casts were identified. Of these, approximately 10% (50/476) were randomly selected through PROC SURVEYSELECT statements in SAS 9.4 and measured for a second time after 2 weeks. Interclass correlation coefficients (ICCs) and Bland–Altman analysis were used to quantify statistically the intra-rater reliability of crowding and irregularity measurements in millimeters in each arch (i.e., upper incisor alignment, lower incisor alignment, upper incisor irregularity, and lower incisor irregularity) (Bland and Altman 1986). For all repeated measurements, the ICCs were >0.98, which indicates excellent reliability (Table 1.4). In addition, the Bland–Altman analysis for all measurements included a zero value in the 95% confidence interval, indicating the lack of systematic bias and that differences between the two measurements occasions were because of random causes. Further verification was made through visually examining the Bland–Altman plots, which confirmed our observations of a small range of differences between the two measurement occasions for all predictors (i.e., upper incisor alignment, lower incisor alignment, upper incisor irregularity, and lower incisor irregularity) (Figure 1.3).

The Association Between Malalignment and Periodontal Disease

Chronic diseases are the main cause of mortality and disability globally (Miniño 2011). In the dental literature, chronic systemic illnesses such as cardiovascular disease and diabetes have been linked to periodontal disease (Cullinan and Seymour 2013). Some recent studies even suggest a link between periodontal disease and cancer (Fitzpatrick and Katz 2010). In the United States, an analysis of the most recent data of the National Health and Nutrition Examination Survey (NHANES 2009–2010) showed that nearly one-half (47%) of the population had periodontitis (Eke et al. 2012). Recognition of the causal risk factors for periodontal disease is an essential tactic to help plan preventive measures and control its extensive spread and subsequent underlining harmful systematic connections.

Dental crowding and malalignment offer a poor environment for maintaining periodontal health. This is primarily because of food retention and subsequent plaque accumulation, which are harmful to the periodontal tissues (Iiellgrcn 1956). Identifying dental crowding or incisor irregularity as a risk factor for periodontal disease may indeed prioritize orthodontic treatment as a preventive measure over its esthetic or functional indicators. However, this action is not easily accomplished because periodontal disease advances moderately and generally has latent periods of slow or no activity (Dye et al. 2014). To overcome such obstacles in recognizing the causal risk factors for periodontal disease, a prospective longitudinal study design should accordingly be adopted with a long follow-up time and a large sample size.

In the current literature, three cross-sectional studies (Poulton and Aaronson 1961; Buckley 1972; Geiger et al. 1974) investigated the association between dental crowding and periodontal disease. Buckley (Buckley 1972) found a significant correlation between lower incisor crowding and Russell's Periodontal Index ($r = +0.14$, $P < 0.05$), whereas Poulton and Aaronson (Poulton and Aaronson 1961) did not find a significant association between the two entities. Furthermore, Geiger et al. (Geiger et al. 1974) did not report a significant association between overall dentition crowding and the Tooth Destruction Index ($P > 0.05$). These studies used different methods for assessing dental crowding and periodontal disease. In addition, they did not account for clinical attachment loss or bone loss as parameters in the periodontal disease evaluation (Table 1.5).

One cohort study (Ingervall et al. 1977) and five cross-sectional studies (Ainamo 1972; Silness and Roynstrand 1985; Helm and Petersen 1989b; Jensen and Solow 1989; Ngom et al. 2006) independently examined the effect of dental irregularity on periodontal disease. Among the five cross-sectional studies (Ainamo 1972; Silness and Roynstrand 1985; Helm and Petersen

1989b; Jensen and Solow 1989; Ngom et al. 2006), two studies (Silness and Roynstrand 1985; Ngom et al. 2006) reported a significant association between irregularity and pocket depth, one study (Silness and Roynstrand 1985) in the overall dentition and one study (Ngom et al. 2006) in the mandibular teeth. In addition, two studies (Jensen and Solow 1989; Abu Alhaija and Al-Wahadni 2006) have investigated the relationship between dental irregularity and bone loss in the mandibular arch: one study (Jensen and Solow 1989) reported a significant inverse association and another study (Abu Alhaija and Al-Wahadni 2006) found no significant association. Furthermore, alignment was significantly associated with clinical attachment loss in mandibular dentition in one study (Ngom et al. 2006). These studies had several limitations such as the use of neither reliable nor validated instruments in the irregularity measurements, lack of accounting for confounding factors, and limiting the definition of periodontal disease to certain parameters.

Moreover, Ingervall et al. (Ingervall et al. 1977) evaluated pocket depth and bone loss in the only cohort study that exists on the effect of dental irregularity on periodontal disease development. They reported no association between dental irregularity and either periodontal disease parameter. Their study had several limitations, which included a short follow-up period(140 days), small sample size (n = 50), lack of accounting for attachment loss, and the use of neither reliable nor validated methods in tooth irregularity measurements. This cohort study attempted to investigate the association between dental irregularity and periodontal disease; however, its limitations did not fill the gaps in the current knowledge of identifying whether misalignment is a true risk factor for periodontal disease (Table 1.6).

Indices combining dental crowding and irregularity were used in four cross-sectional studies (Ainamo 1972; Katz 1978; Hörup et al. 1987; Staufer and Landmesser 2004). One study (Staufer and Landmesser 2004) reported a significant association with such indices and pocket depth, whereas another study (Katz 1978) reported a no significant relationship with pocket depth. In addition, clinical attachment loss was examined in two studies (Jukka Ainamo 1972; Hörup et al. 1987), which found no significant association with dental crowding and irregularity (Table 1.7). Across these studies, several limitations were clear such as the disregarding of potential confounding factors in the design and analysis, using combined indices that could bias the results, and limiting the definition of periodontal disease to certain parameters. To the best of our knowledge, the association between dental malalignment and periodontal disease was not evaluated in a high-quality prospectively designed longitudinal study with a long-term follow up.

The Association Between Malalignment and Tooth Loss

To the best of our knowledge, no published studies have investigated the association between malalignment and tooth loss.

The Association Between Malalignment and Dental Caries

Despite the existing comprehension of caries prevention and treatment, dental caries prevalence remains unreasonably high among the U.S. population, and continues to be a substantial problem for all age groups. The most current examined data from the National Health and Nutrition Examination Survey (NHANES 2005–2008) showed that 20% of the U.S. population experienced untreated cavities, and that 75% of individuals had at minimum a single filling (Dye, et al. 2012).

Effectively planning preventive strategies against the occurrence of early carious stages should be of primary concern to control such widespread disease. One tactic of preventing caries at the early phases of an individual’s lifetime is to identify its causal risk factors. Dental crowding and alignment are sources of food collection and plaque retention (Helm and Petersen 1989a; Helm and Petersen 1989b). It seems intuitive that dental crowding or alignment perhaps increases the occurrence of caries. Robust evidence of the association between dental crowding, alignment and caries would consequently make orthodontic interventions a priority as a preventive measure aimed at improving oral health, beyond its esthetic, and functional indicators (Hafez et al. 2012).

In the current literature, no studies have investigated the effect of dental crowding solely on dental caries, whereas the association between tooth irregularity and dental caries have been examined in three cross-sectional studies in which incisor irregularity was positively associated with dental caries (Hixon et al. 1962; Helm and Petersen 1989a; Buczkowska-Radlinska et al 2012). However, in one study (Hixon et al.1962), a significant inverse relationship between irregularity and dental caries was noted in the maxillary posterior region (Table 1.8). Several limitations were identified in these studies such as the use of neither validated nor reliable methods to measure irregularity, and lack of accounting for confounding factors in the design or analysis.

Six cross-sectional studies (Roder and Arend 1971; Katz 1978; Addy et al. 1988; Stahl and Grabowski 2004; Staufer and Landmesser 2004; Alsoliman 2010) investigated dental crowding and irregularity together, and used specific indices that incorporated both entities in relation to dental caries. Overall dental crowding or alignment was negatively correlated in one study (Alsoliman 2010), but not significantly associated in another study (Addy et al. 1988). In the anterior maxillary segment, one study (Roder and Arend 1971) found a significant positive association between dental crowding and irregularity together and caries. In contrast, another study (Ralph Katz 1978) found a significant negative association between dental crowding together with irregularity in association with caries in the maxillary anterior teeth. In the lower anterior segment, one study (Staufer and Landmesser 2004) reported no association between dental crowding and irregularity together in relation to caries, whereas one study (Stahl and Grabowski 2004) reported a significant association between posterior crowded or misaligned segments and caries (Table 1.9). Among other limitations, these contradictory results are primarily the consequence of disregarding the differences between dental irregularity and crowding because irregularity deals with labiolingual displacement of the teeth, whereas crowding entails the actual displacement of teeth because of the lack of excess space (Staley and Reske 2010).

Hfez et al. (Hafez et al. 2012) recently published a systematic review to assess the relationship between dental crowding and the development of dental caries. In their review, they found contradictory results among the eight cross-sectional studies. Such results were attributed to the multifactorial and dynamic nature of dental crowding and caries. However, in their assessment the authors did not illustrate or report the differences between dental crowding and irregularity measurements. They instead simply reported finding heterogeneity in the design and in the indices used for crowding and caries evaluation across the eight studies. This systematic review concluded that there is a need for longitudinal studies to clarify if dental crowding is a true risk factor in dental caries development.

To the best of our knowledge, the association between dental malalignment and dental caries has not been reported in a prospectively designed longitudinal study.

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Table 1.1. Indices and methods used to measure dental malalignment or irregularity in relation to dental caries and periodontal disease

Type of Index		
Crowding Indices	**Irregularity Indices**	**Combined Crowding and Irregularity Indices**
Validated and Questionably Reliable Methods		
Occlusal Feature index (OFI)	None	None
Type of Index		
Invalid and Unreliable Methods		
Geiger Method (Geiger et al. 1974)	(1) Malposition in the contact area that is equal to or greater than the thickness of the incisal edge (2) Any deviation of 2 mm in any of the two sections: anterior (i.e., incisor) or lateral (i.e., canine and premolars) (3) Displaced by 2 mm and/or rotated 15° or more from the normal position in the arch	(1) Any tooth rotated, or out of line for which space have to be created to allow malalignment correction (2) 0.8 mm increment method developed by Björk (Björk 1963) (3) Malalignment index of Massler and Frankel (MIM) (4) Malalignment index of VanKirk and Pennel (MIV) (5) Malalignment index of Kirk and Pennell (MIKP) (6) Modified Lundstrom Index (7) Standardized technique for recording the alignment of individual teeth (STRAIT)

Table 1.2. Time-related changes in incisor alignment in the upper and lower arches

Measure (mm)	**T1 [mean (SD)]**	**T2 [mean (SD)]**	**Mean Difference (SD)** [a]	**Range**	***P* Value**
Maxillary anterior alignment	0.82 (1.51)	0.78 (1.53)	0.04 (0.12)	(0.001-0.08)	0.05
Mandibular anterior alignment	-0.49 (2.13)	-0.45 (2.05)	-0.04 (0.19)	(-0.1 to 0.02)	0.20
Maxillary anterior irregularity	3.25 (2.08)	3.22 (2.0)	0.03 (0.30)	(-0.07 to 0.13)	0.57
Mandibular anterior irregularity	3.76 (2.09)	3.75 (2.10)	0.01 (0.31)	(-0.08 to 0.11)	0.80

-[a] A positive sign indicates an increase towards crowding in the alignment status, whereas a positive sign indicates a decrease in the irregularity status.

Table 1.3. Time-related changes in incisor alignment in the upper and lower arches, stratified by the actual presence of incisor crowding (aTSALD <0 mm) or ideal alignment/spacing

Characteristics	**mean Difference (SD)** [a]	**Range**	***P* Value**
Maxillary incisor alignment (aTSALD <0 mm; n = 9)			
Maxillary anterior alignment	0.11 (0.17)	(-0.02 to 0.24)	0.08
Maxillary anterior irregularity	0.09 (0.29)	(-0.14 to 0.31)	0.39
Maxillary incisor ideal alignment/spacing (aTSALD ≥0 mm; n = 30)			
Maxillary anterior alignment	0.02 (0.09)	(-0.02 to 0.05)	0.31
Maxillary anterior irregularity	0.01 (0.31)	(-0.11 to 0.13)	0.86
Mandibular incisor alignment (aTSALD <0 mm; n = 21)			
Mandibular anterior alignment	-0.10 (0.23)	(-0.20 to 0.01)	0.07
Mandibular anterior irregularity	-0.05 (0.32)	(-0.19 to 0.1)	0.51
Mandibular incisor ideal alignment/spacing (aTSALD ≥0 mm; n = 18)			
Mandibular anterior alignment	0.03 (0.08)	(-0.01 to 0.07)	0.17
Mandibular anterior irregularity	0.08 (0.30)	(-0.06 to 0.23)	0.25

[a] A positive sign indicates an increase towards crowding in the alignment status, whereas a positive sign indicates a decrease in the irregularity status.
aTSALD, anterior tooth size-arch length discrepancy; SD, standard deviation.

Table 1.4. Intrarater reliability values showing the interclass correlation coefficient values, mean difference, And limit of agreement for incisor alignment and irregularity obtained at two separate occasions (n = 50)

Measurement	**ICC**	**Mean Difference (SD) (mm)**	**Limit of Agreement (mean difference ± 1.96 SD) (mm)**
Upper incisor alignment	0.984	- 0.11 (0.52)	(-0.25 to 0.04)
Lower incisor alignment	0.980	0.10 (0.48)	(-0.03 to 0.24)
Upper incisor Irregularity	0.987	- 0.10 (0.47)	(-0.23 to 0.03)
Lower incisor Irregularity	0.980	- 0.04 (0.43)	(-0.16 to 0.09)

ICC, interclass correlation coefficient; SD, standard deviation.

Table 1.5. Evidence table summarizing the studies on the association between dental crowding and periodontal disease

Authors **Study Design**	**Study Population**	**Measurements**	**Results**	**Direction of Association** [a]	**Limitations**
Poulton and Aaronson 1961 **Cross-sectional**	Sample: n = 908 Race: Caucasians Age: 17–26 years old	Periodontal: Russell's Periodontal Index (RPI) Crowding: Occlusal Feature Index (OFI)	ANOVA: Lower incisor crowding vs. noncrowded *P*>0.05	**x**	• Did not control for confounding factors • Did not measure oral health status • Did not account for attachment loss • Did not account for bone loss • Used an invalid method to measure periodontal disease
Buckley 1972 **Cross-sectional**	Sample: n = 954 Race: not reported Age: 14–54 years old	Periodontal: (RPI Crowding: OFI	Spearman correlation coefficient: Lower incisor crowding vs. RPI R = +0.14 *P* < 0.05	+	• Did not control for confounding factors • Did not measure oral health status • Did not account for attachment loss • Did not account for bone loss • Used an invalid method to measure periodontal disease • Race was not reported
Geiger et al. 1974 **Cross-sectional**	Sample: n = 516 Race: Caucasian (64.5%), African-American (31.2%), and others (4.3%) Age: 21 years old and older	Periodontal: Tooth Destruction Index (TDI) Crowding: Scores in a range of 1–4 by two orthodontists	Chi-square test: Crowded vs. noncrowded *P* > 0.05	**x**	• Used faulty methods for crowding measurements • Did not account for bone loss • Did not account for attachment loss • Did not measure oral health status

[a] Direction of association: "-", negative association, "x", no association; "+", positive association. ANOVA, analysis of variance.

Table 1.6. Evidence table summarizing the studies on the association between tooth irregularity and periodontal disease

Authors Study Design	Study Population	Measurements	Results	Direction of Association [a]	Limitations
Ingervall et al. 1977 **Longitudinal Follow Up: at 40 days and 140 days**	Sample: n = 50 Race: not reported Age: 35–44 years	Periodontal: Pocket depth (PD), and alveolar bone loss (ABL) Irregularity: Displaced by 2 mm and/or rotated 15° or more from the normal position in the arch	t-Test (PD and bone loss): At all examinations: Irregularity vs. PD and BL $P > 0.05$	x	• Used a faulty method to measure irregularity measurements • Did not account for attachment loss • Race not reported • Short follow-up period • Small sample size
Silness and Roynstrand 1985 **Cross-sectional**	Sample: n = 144 Race: not reported Age: 15 years	Periodontal: Pocket depth Irregularity: Irregularity defined as two adjoining proximal surfaces deviated from a trace line drawn on the anterior incisal edges	t-Test (pocket depth): Irregular vs. nonirregular $P < 0.0001$	+	• Did not control for confounding factors • Faulty error in irregularity measurements • Did not measure oral health status • Did not account for attachment loss • Did not account for bone loss • Race was not reported

Helm and Petersen 1989b **Cross-sectional**	Sample: n = 119 Race: Not reported Age: 33–39 years	Periodontal: WHO criteria (1987): Pocket depth (>3.5 mm) Irregularity: Any deviation of 2 mm in any of the two sections: anterior (i.e., incisor) or lateral (i.e., canine and premolars)	Multiple regression analysis [pocket depth (>3.5)]: Maxillary irregularity vs. regular $\beta = +1.2$ $P>0.05$ Mandibular irregularity vs. Regular $\beta = +0.6$ $P>0.05$	**x** **x**	- Used faulty method for the irregularity measurement - Did not measure oral health status - Did not account for attachment loss - Did not account for bone loss - Race was not reported
Jensen and Solow 1989 **Cross-sectional**	Sample: n = 27 Race: not reported Age: 29–57 years periodontal patients	Periodontal: Bone loss (absolute bone level, and relative bone level) Irregularity: Overlap of 2 mm or more	t-Test (bone loss): Irregularity vs. regular $P < 0.001$ t-Test (relative bone loss): Irregularity vs. regular $P < 0.001$	– –	- Used faulty method for the irregularity measurement - Did not control for confounding factors - Did not measure of oral health status - Did not account for attachment loss - Did not account for pocket depth - Race was not reported - Small sample size
Ngom et al. 2006 **Cross-sectional**	Sample: n = 119 Race: Not reported Age: 33–39 years	Periodontal: Clinical attachment loss (CAL), pocket depth (PD), and gingival recession (GR) Irregularity: Index of complexity, outcome and need (ICON)	Spearman correlation coefficient: Maxillary irregularity vs. CAL and PD $P>0.05$ Mandibular irregularity vs. CAL $R = +0.22 < 0.05$ Mandibular irregularity vs. PD $R = +0.24; P < 0.05$	**x** + +	- Used faulty method for irregularity measurement - Did not control for confounding factors - Race was not reported - Did not account for bone loss

Abu Alhaija and Al-Wahadni 2006 **Cross-sectional**	Sample: n = 80 Race: Not reported Age: mean of 12.8 years	Periodontal: Pocket depth (PD), and alveolar bone loss (ABL) Irregularity: Mesiodistal overlap and labiolingual displacement measured in millimeters	Spearman correlation coefficient: Mandibular irregularity vs. PD and alveolar bone loss (ABL) $P > 0.05$	**x**	• Did not control for confounding factors • Race was not reported • Did not account for clinical attachment loss

[a] Direction of association: "-", negative association, and "x", no association, and "+", positive association.

Table 1.7. Evidence table summarizing the studies on the association between both tooth irregularity and dental crowding and periodontal disease

Authors **Study Design**	**Study Population**	**Measurements**	**Results**	**Direction of Association** [a]	**Limitations**
Ainamo 1972 **Cross-sectional**	Sample: n = 80 Race: Not reported Age: 19 – 22 years old	Periodontal: Clinical attachment loss (CAL) Crowding and Irregularity: Malalignment index of Kirk and Pennell (MIKP)	ANOVA: Maxillary incisor crowding/irregularity vs. aligned maxillary incisors < 0.05 Mandibular incisor crowding/irregularity vs. aligned mandibular incisors < 0.05	+ +	• Did not control for confounding • Did not account for pocket depth • Did not account for bone loss • Race was not reported
Katz R, 1978 **Cross-sectional**	Sample: n = 160 Race: Caucasian Age: 16-25 years old	Periodontal: Periodontal pocket depth index (PPDI) Crowding and Irregularity: Malalignment index of Massler and Frankel (MIM), and the malalignment index of VanKirk and Pennel (MIV)	T-Test (Periodontal pocket depth index): Crowding vs. noncrowded $P>0.05$	**x**	• Sex was not reported • Did not account for attachment loss • Did not account for bone loss
Hörup et al. 1987 **Cross-sectional**	Sample: n = 422 Race: not reported Age: 35-44 years old	*Periodontal*: Loss of attachment (< 4 mm) Crowding and Irregularity: Crowding: 0.8 mm increment method developed by Björk et al.	Chi-Square Test (Loss of attachment): Crowding vs. noncrowded X2 = (-0.03), $P>0.05$	**x**	• Did not control for confounding factors • Did not obtain the baseline oral health status • Did not account for pocket depth • Did not account for bone loss • Race was not reported

Staufer and Landmesser, 2004 **Cross-sectional**	Sample: n = 125 Race: not reported Age: 18-34 years old	Periodontal: Pocket depth (PD) Crowding and Irregularity: Lundstrom Index	Chi-Square Test (Pocket depth): Lower anterior teeth crowding vs. noncrowded Lower anterior teeth $P < 0.001$	+	• Did not control for confounding factors • Did not measure the oral health status • Did not account for attachment loss • Did not account for bone loss • Race was not reported

[a] Direction of association: "-", negative association; and "x", no association; "+", positive association.

Table 1.8. Evidence table summarizing the studies on the association between teeth irregularity and coronal caries

Authors **Study Design**	**Study Population**	**Measurements**	**Results**	**Direction of Association** [a]	**Limitations**
Hixon et al. 1962 **Cross-sectional**	Sample: n = 126 Race: Caucasian mean age: 18.3 years	Caries: DFS index (Percent of decayed and filled proximal surfaces) Irregularity: Irregular defined as malposition in the contact area that is equal or greater than the thickness of the incisal edge	Chi-squared test (percent of decayed and filled proximal surfaces): Irregular mandibular anterior teeth vs. Satisfactory mandibular anterior teeth $P < 0.01$ Irregular maxillary anterior teeth vs. satisfactory maxillary anterior teeth $P < 0.01$ Irregular maxillary posterior teeth vs. satisfactory maxillary posterior teeth $P < 0.01$	+ x –	• Did not control for confounding • Used a faulty method for irregularity measurements • Did not measure the oral health status
Helm and Petersen 1989a **Cross-sectional**	Sample: n = 119 Race: Not reported Age: 33–39 years	Caries: DMFS index Irregularity: Any deviation of 2 mm in any of the two sections: anterior (incisor) or lateral (canine and premolars)	Multiple regression analysis (decayed surfaces): Irregular maxillary anterior teeth vs. nonirregular maxillary anterior teeth $\beta = 0.48$ $P < 0.05$	+	• Used a faulty method for irregularity measurements • Did not measure the oral health status • Race was not reported
Buczkowska-Radlinska et al. 2012 **Cross-sectional**	Sample: n = 225 Race: not reported Age: 3–19 years	Caries: dmft/DMFT index Irregularity: Displaced by 2 mm and/or rotated 15° or more from the normal position in the arch	Multiple regression analysis (dmft/DMFT): Anterior dental irregularity vs. normally aligned anterior teeth OR = 3.71 95% CI = 1.27-10.85; $P = 0.02$	+	• Race was not reported • Used a faulty method for irregularity measurements

[a] Direction of association: “-“, negative association; “x”, no association, and “+”, positive association.

CI, confidence interval; DFS, decayed and filled surface; DMFT, decayed, missing, and filled teeth; DMFS, decayed, missing, and filled surface; OR, odds ratio.

Table 1.9. Evidence table summarizing the studies on the association between tooth irregularity and dental crowding and coronal caries

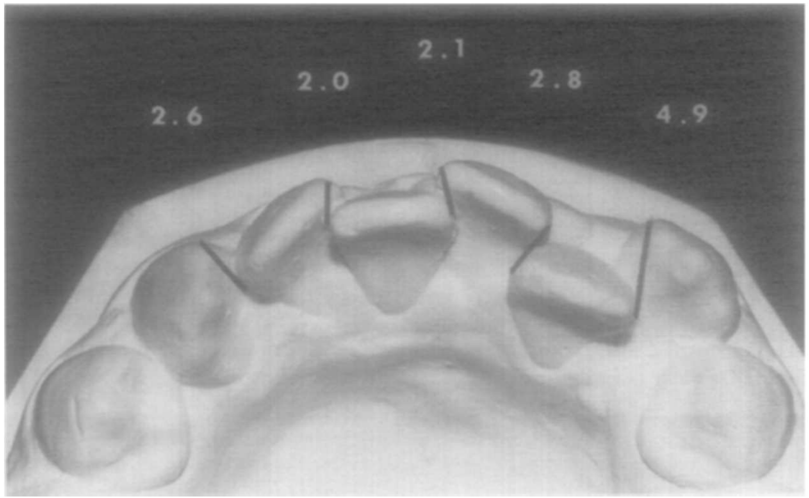
Authors **Study Design**	**Study Population**	**Measurements**	**Results**	**Direction of Association** [a]	**Limitations**
Roder and Arend 1971 **Cross-sectional**	Sample: not reported Race: not reported Age: 14–16 years (girls)	Caries: DMFS index Crowding and irregularity: 0.8 mm increment method developed by Björk et al.	t-Test: Crowded/Irregular maxillary anterior teeth vs. normally aligned maxillary anterior teeth $P < 0.05$	+	• Did not control for confounding factors • Did not measure the oral health status • Race was not reported • Sample size was not reported
Katz R 1978 **Cross-sectional**	Sample: n = 160 Race: Caucasian Age: 16–25 years	Caries: DMFS index Crowding and irregularity: Malalignment index of Massler and Frankel (MIM) and the malalignment index of VanKirk and Pennel (MIV).	t-Test: Crowded/irregular maxillary anterior teeth vs. normally aligned maxillary anterior teeth $P < 0.05$	–	• Sex was not reported
Addy et al. 1988 **Cross-sectional**	Sample: n = 1,015; for a total of 2,674 pairs of teeth Race: not reported Age: 11.5–12.5 years	Caries: DFS index Crowding and Irregularity: Standardized technique for recording alignment of individual teeth (STRAIT)	Four-way hierarchical analysis: Crowded/irregular vs. noncrowded/irregular $P > 0.05$	**x**	• Did not measure the oral health status • Race was not reported

Stahl and Garbowski 2004 **Cross-sectional**	Sample: n = 8,864 Race: not reported Age: Boys: mean age, 4.5 years; Girls: mean age, 8.9 years	Caries: DMFS index Crowding and irregularity: Any tooth rotated or out of line for which space has to be created to allow malalignment correction	Mann–Whitney *U* Test: Posterior crowded/irregular segment vs. normal occlusion $P = 0.02$	+	• Did not control for confounding factors • Used a faulty method for crowding/irregularity measurements • Did not measure the oral health status • Race was not reported
Staufer and Landmesser 2004 **Cross-sectional**	Sample: n = 125 Race: not reported Age: 18–34 years	Caries: DMF index Crowding and irregularity: Modified Lundstrom Index	Mann–Whitney *U* test: Lower anterior crowding/irregularity vs. normally aligned lower anterior teeth $P > 0.05$	**x**	• Used a faulty method for crowding/irregularity measurements • Did not measure the oral health status • Race was not reported
Alsoliman 2010 **Cross-sectional**	Sample: not reported Race: not reported Age: 9–13 years	Caries: DMFT Index Crowding and irregularity: Any tooth rotated or out of line for which a space has to be created to allow malalignment correction	Spearman correlation coefficient: Crowding/irregularity vs. dmft Rs = -0.07 $P = 0.04$	–	• Sample size was not reported • Race was not reported • Used a faulty method for crowding/irregularity measurements • Did not measure the oral health status

[a] Direction of association: “-”, negative association; “x”, no association, and “+”, positive association.

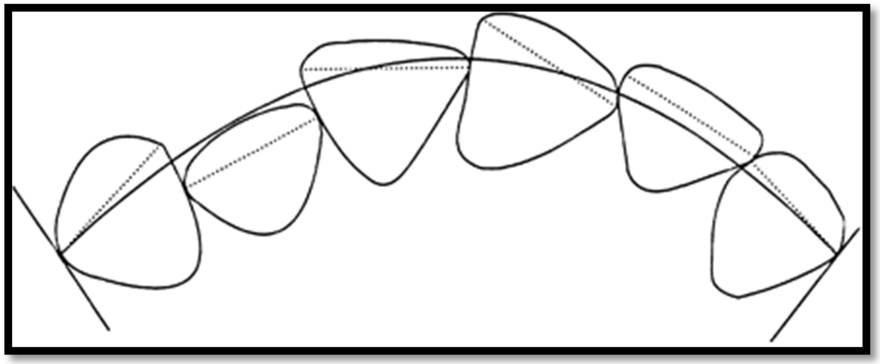
DFS, decayed and filled surface; DMFT, decayed, missing, and filled teeth; DMFS, decayed, missing, and filled surface.

Figure 1.1. Schematic representation of the incisor "irregularity index" developed by Little (1975).



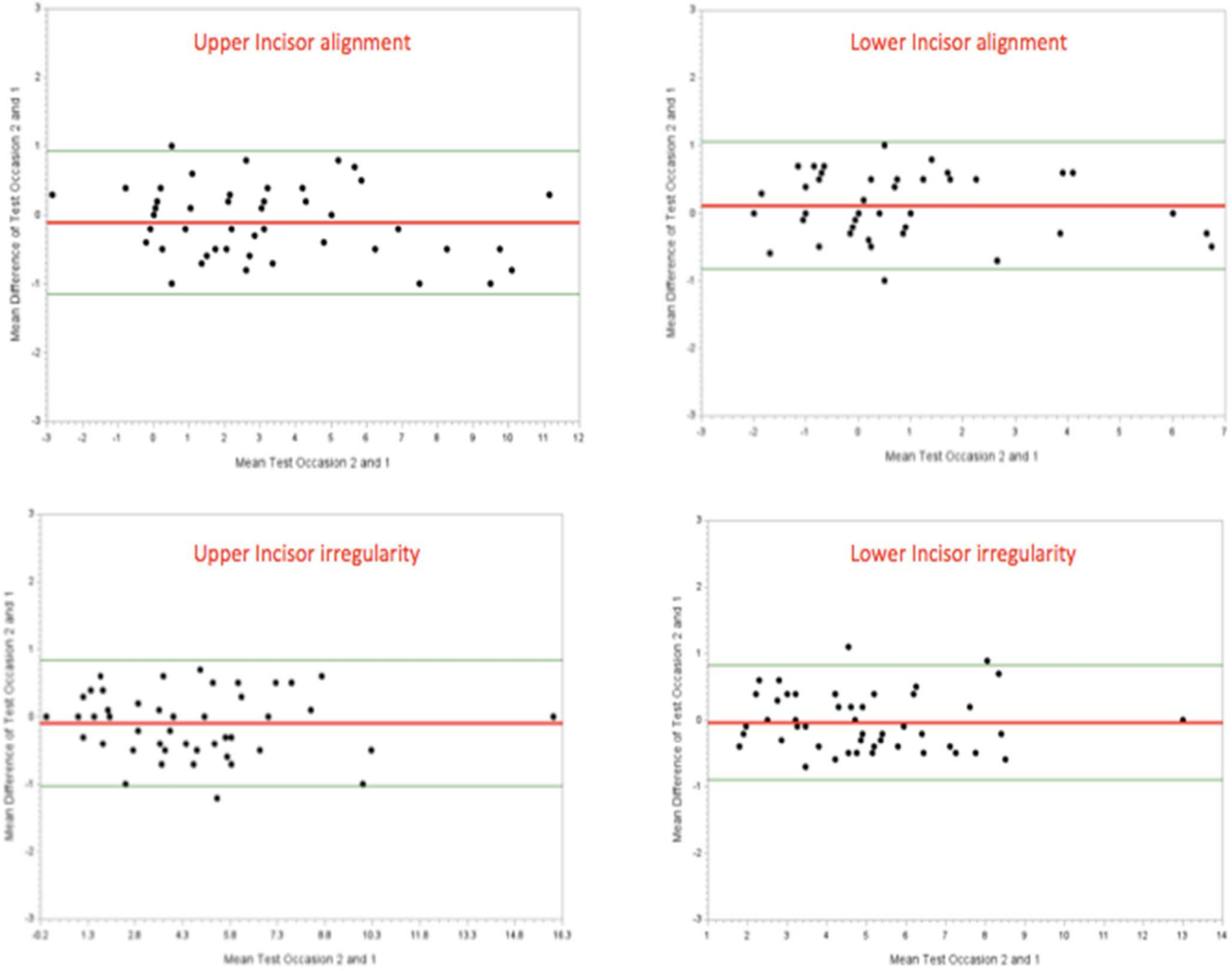
Source: Little RM. 1975. The irregularity index: a quantitative score of mandibular anterior alignment. Am J Orthod. 68(5):554–563.

Figure 1.2. The anterior tooth size-arch length discrepancy is measured by subtracting the sum of the anterior teeth width (broken line) and the anterior arch perimeter (solid line).



Source: Bondevik O. 2007. Differences between high-and low-angle subjects in arch form and anterior crowding from 23 to 33 years of age. Eur J Orthod. 29(4):413–416.

Figure 1.3. The Bland–Altman plots for four predictors: upper incisor alignment, lower incisor alignment, upper incisor irregularity, and lower incisor irregularity.



Upper Incisor alignment

Lower Incisor alignment

Upper Incisor irregularity

Lower Incisor irregularity

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Incisor Malalignment and the Risk for Periodontal Disease

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ABSTRACT

This longitudinal study aimed to assess if maxillary and mandibular incisor malalignment is a risk factor for anterior periodontal disease. Thirteen triennial dental examinations were available (1971–2009), which included information concerning pocket depth (PD), alveolar bone loss (ABL), and clinical attachment loss (CAL). Calibrated periodontists served as dental examiners. Anterior periodontal disease outcomes were defined as per arch sum of the maximum PD, CAL, and sum of teeth with any ABL in the anterior sextants. Only 400 and 408 measurable plaster casts of the upper and lower arches, respectively, were available for baseline measurements (1971–1976). The incisor alignment status was defined by two methods: the anterior tooth size–arch length discrepancy (aTSALD) index and Little's Irregularity Index (LII). Adjusted fixed/mixed effect models were used to compute the beta (β) estimates and 95% confidence intervals (95% CIs) of the amount of change in periodontal disease outcomes by the level of alignment status. At baseline, the participants' mean age was approximately 50 years. In the upper anterior arch, crowding and spacing were significantly associated with increased per arch sum of the maximum PD (β = 0.70 and 95% CI = 0.20-1.21, and β = 0.49 and 95% CI = 0.06-0.91, respectively). Maxillary incisor irregularity was positively associated with increased per arch sum of maximum CAL (β = 2.10, 95% CI = 0.60-3.59). In the anterior mandibular arch, incisor crowding and irregularity were significantly associated with increased per arch sum of maximum PD (mild crowding: β = 0.47, 95% CI = 0.01-0.93; severe irregularity: β = 0.94, 95% CI = 0.50-1.38), CAL (moderate to severe crowding: β = 2.12, 95% CI = 0.46-3.77; moderate irregularity: β = 1.54, 95% CI = 0.31-2.77; severe irregularity: β = 2.30, 95% CI = 0.79-3.81), and the sum number of teeth with ABL (mild and moderate and severe crowding: β = 0.45, 95% CI = 0.08-0.82; and β = 0.45, 95% CI = 0.13-0.83, respectively; moderate irregularity: β = 0.34, 95% CI = 0.06 – 0.62). Incisor malalignment may be associated with periodontal disease progression.

Keywords: periodontitis, malalignment, irregularity, crowding, risk factor, longitudinal study, aging

INTRODUCTION

The prevalence of periodontal disease is a major public health concern globally (Petersen et al. 2005). In the United States, approximately 50% of the adult population (≥30 years) has periodontitis with a 15% and 34% prevalence disparity among different states and counties, respectively (Eke et al. 2015; Eke et al. 2016). Several risk factors have been associated with periodontal disease, and the modification of such factors has an important role in treatment planning and in patient management (Knight et al. 2016; Genco and Borgnakke 2013; AlJehani 2014). However, because of the high prevalence of periodontitis and the importance of the identification and modification of risk factors, much research is warranted.

One often overseen factor is the alignment of teeth. The mechanism by which dental malalignment affects periodontal health is intuitive because dental malalignment offers a poor environment for maintaining periodontal health and causes harm to the periodontal tissue due to food retention and subsequent plaque accumulation (Iiellgrcn 1956). This plausible mechanism appears typically existent in the incisor maxillary and mandibular segments (Jukka Ainamo 1972; Silness and Roynstrand 1985). In the current literature, results from early cross-sectional studies that investigated the association between periodontal disease parameters and anterior malalignment were often controversial owing to several factors such as (1) the use of invalid indices to measure periodontitis and malalignment (e.g., composite indices), (2) difficulty in differentiating between crowding and irregularity, and (3) large statistical variability due to a small sample size (Poulton and Aaronson 1961; Buckley 1972; Jukka Ainamo 1972; Geiger, Wasserman, and Turgeon 1974; Silness and Roynstrand 1985; Helm and Petersen 1989b; Jensen and Solow 1989; Staufer and Landmesser 2004; Ngom et al. 2006; Abu Alhaija and Al-Wahadni 2006). One cohort study (Ingervall et al. 1977) showed no significant association between dental malalignment and either pocket depth or bone loss. The study had several limitations, including a short follow-up period (140 days), small sample size (n = 50) of dental students, lack of accounting for attachment loss, and the use of neither reliable nor validated methods in measuring malalignment. Although this cohort study attempted to investigate the association between dental malalignment and periodontal disease, its limitations did not fill the gaps in the current knowledge of identifying whether misalignment is a true risk factor for periodontal disease.

Identifying dental malalignment as a risk factor for periodontal disease may indeed prioritize orthodontic treatment as a preventive measure over its esthetic or functional indicators. However, this action is not easily accomplished because periodontal disease advances intermittently or in bursts (Socransky et al. 1984; Beck JD and Slade GD 1995). To overcome such obstacles in recognizing risk factors for periodontal disease, a longitudinal study design is needed with a long follow-up time and a relatively large sample size. To the best of our knowledge, the association between dental malalignment and periodontal disease has not been evaluated in a longitudinal study with a long-term follow up. Therefore, the objective of this longitudinal study was to investigate the association between incisor malalignment and periodontitis, as measured by pocket depth, bone loss, and clinical attachment loss.

MATERIAL AND METHODS

Study participants

In 1969, the Department of Veterans Affairs (VA) started a closed-panel Dental Longitudinal Study (DLS) by enrolling 1,231 participants drawn from the parallel VA Normative Aging Study (NAS) with a total of 2,280 non-Hispanic White, healthy, community-dwelling male veterans. The participants had their medical and dental treatment in the private sector and were not patients of the VA care system. Thirteen triennial detailed dental and medical examinations where available (1969–2009) with plaster casts obtained only from the first five recall visits (1969–1985). Our baseline records corresponded to the highest number of collected plaster casts, which were determined at the second triennial examination (1971–1976), accounting for 476 upper and lower casts. Of these, only 400 and 408 measurable plaster casts of the upper and lower arches, respectively, were available for measurements and analysis. In our study, the participants were older adults, were completely dentate in the anterior sextants at baseline, had not undergone orthodontic treatment, and had at least three recall dental examinations between 1971 and 2009 (i.e., approximately 40 years of follow up). All participants signed written informed consent before each examination. The study was approved by institutional review boards at Boston University Medical Center (Boston, MA) and the VA Boston Healthcare System (Boston, MA). This report complies with Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies.

Periodontal health

At every triennial examination, a calibrated periodontist (Edward Loftus, 1969 to 1979; Roy Feldman, 1979 to 1984; Raul Garcia, 1984 to 2009) performed a clinical and radiographic dental examination on all teeth present and, when applicable, recorded the absence of teeth. In our data, the examination of pocket depth (PD) and alveolar bone loss (ABL) in the anterior sextants (maxillary sextant: from 6 to 11; mandibular sextant: from 22 to 27) was available from 1971 to 2009; however, clinical attachment loss in the anterior sextant was only added to the dental examination record in 1981 and last collected in 2009. Thus, by application of the inclusion criteria there was a decrease in the sample size to 350 upper casts, and 358 lower casts available for analysis when CAL was used as an outcome measure. A Williams probe was used to obtain the maximum PD (i.e., mesial, distal, labial, and lingual) and CAL (i.e., mesial, and distal) per tooth and recorded in an interval score scale (score 0: ≤2 mm; score 1: >2 to ≤3 mm; score 2: >3 to <5 mm; and score 3: ≥5 mm). For PD and CAL, the sum of maximum value per tooth in a the anterior area per arch was computed (Dietrich et al. 2008). Through the use of periapical radiographs taken with a paralleling method with Rinn holders and by utilizing a modified Schei ruler method (Schei et al. 1959), which superimposes a translucent ruler on the radiograph with assigned reference points at the cementoenamel junction (CEJ) and root apex, ABL scoring was applied to interproximal sites per tooth using a 20% increment (score 0: no bone loss; score 1: bone loss ≤20%; score 2: bone loss >20% and ≤40%; score 3: bone loss >40% and ≤60%, score 4: bone loss >60% and ≤80%, score 5: bone loss >80%). For ABL, the sum number of teeth with any bone loss (i.e., >0% ABL) per arch was computed (Ng et al. 2013). Reliability was only measured in PD and ABL, which indicated a good reliability (>0.4 kappa statistics) (Landis and Koch 1977) in 24 participants and 25 participants, respectively.

In addition, after rinsing with a disclosing agent, an ordinal scale was used to record plaque (score 0: none; score 1: interproximal surfaces only; score 2: interproximal surfaces continuing onto labial or lingual sites; and score 3: all surfaces covering more than two-thirds of the tooth). Supragingival calculus was measured by an ordinal scale (score 0: none; score 1: discontinuous flecks; score 2: non-continuous band on tooth surfaces; and score 3: continuous band on tooth surfaces). Instrument handles were used to assess mobility by pressing on the buccal and lingual surfaces of the tooth and movement was scored by an ordinal scale (score 0: none; score 1: <0.5 mm; score 2:

0.5–1.0 mm; and score 3: >1.0 mm). For each anterior arch, we calculated the mean plaque, calculus, and mobility scores.

Incisor Malalignment and Irregularity

Plaster dental casts obtained at baseline(1971–1976) were used to measure anterior dental alignment status and incisor irregularity in the anterior maxillary and mandibular arches (maxillary sextant: from 6 to 11; mandibular sextant: from 22 to 27). In each arch, the space available minus the space required represented the amount of anterior dental alignment, as per the anterior tooth size–arch length discrepancy (aTSALD) index (Harris et al. 1987). Space required was obtained through the sum of the maximum mesiodistal widths of anterior teeth, canine to canine, using a digital caliper. Space available was determined through the arch best fit using a flexible ruler from the maximum point of canines distally. The flexible ruler was placed on the incisor surfaces per arch, and the arch best fit was identified as the even curve accommodating most teeth. For instances in which an equal number of anterior teeth was displaced in a different manner (i.e., two anterior teeth displaced labially, and two anterior teeth displaced lingually), a midpoint curve was used as a guide for the arch best fit. The severity of dental malalignment was categorized using the Index of Orthodontic Treatment Needs (spacing: >0 mm; ideal alignment: 0 mm; mild crowding: <0 mm and ≥ -2 mm; moderate to severe crowding: < -2 mm) (Brook and Shaw 1989). In the maxillary arch, any crowding was grouped into one category because of the limited number of severe cases. Incisor irregularity was determined by using Little's Irregularity Index (LII) criterion, which defines irregularity as the labiolingual linear displacement of anatomical contact points obtained through a digital caliper placed parallel to the occlusal plane (Little 1975). The severity of incisor irregularity was modified into three categories (no/mild irregularity: ≥0 mm and <4 mm; moderate irregularity: ≥4 mm and ≤6 mm; severe irregularity: >6 millimeters) (Little 1975). Alignment and irregularity status in the upper and lower incisors were stable as statistically tested ($P > 0.05$, based on the paired t-test) in a convenience sample of 39 individuals (90% power) who had 9–10 years follow-up casts after the baseline records. Intra-rater reliability of more than 10% of randomly selected dental casts showed an excellent interclass correlation of >0.98 for all four predictors (i.e., upper incisor alignment, lower incisor alignment, upper incisor irregularity, and lower incisor irregularity).

Other Information

Covariates in our data included age in years, income level (low: <\$20,000; middle: ≥\$20,000 and <\$30,000; high: ≥\$30,000), educational level (high school or some college, and college graduate), current smoking status (yes or no), number of medications, flossing (never or at least one a month), brushing (once a week or less, twice a week or more), quality and quantity of saliva (limited, copious), any dental treatment in the past year, any gum treatment in the past year (yes or no), any prophylaxis cleanings in the past year (yes or no), number of teeth remaining in each anterior arch, and number of teeth remaining in the whole mouth.

Statistical Methods

All statistical analyses were conducted using SAS software version (9.4). Analysis of variance (ANOVA) and the chi-square test were used in the univariate and bivariate analysis to identify any statistical association with dental alignment and irregularity as evaluated by LLI and aTSALD. Multivariate linear fixed/mixed effect models were used to estimate the effect of dental alignment (i.e., LLI, aTSALD) on the progression of periodontitis (i.e., the sum of maximum PD/CAL in millimeters and the sum number of teeth with ABL) in each specific arch. Correlated outcome data were controlled for by using a repeated-measure model with an autoregressive within-subject correlation matrix and a time factor was used (i.e., time) to cluster the observations. Confounders were included if they were significant at a 0.05 level or if they altered the coefficient of the main variable by more than 10% in instances in which the main association was significant. Statistical significance was evaluated at the 0.05 level.

RESULTS

The unit of analysis in this longitudinal study was each of the anterior arches separately (i.e., anterior maxillary arch and anterior mandibular arch). For all four predictors, the mean age was approximately 50 years at baseline. Anterior plaque and calculus scores were higher in the mandibular anterior arch (11.6 ± 3.4 and 9.7 ±4.5, respectively) than in the maxillary anterior arch (7.4 ± 3.6 and 3.8 ± 4.3, respectively). Anterior mobility scores were higher in the anterior maxillary arch (0.7 ± 1.7) than in the anterior mandibular arch (0.3 ±1.3). Periodontal health outcomes in the anterior maxillary arch showed the following variations: the sum of the maximum PD varied from 0–18 (mean, 1.9 ± 3.5 mm), the sum of maximum CAL varied from 0–36 (mean, 2.4 ± 5.9 mm), and the sum number of teeth with ABL varied from 0–6 (mean, 2.0 ± 2.2 mm). In the anterior mandibular arch, there was a higher occurrence of periodontal disease: the sum of the maximum PD varied from 0–17 (mean, 1.4 ± 2.8 mm), the sum of the maximum CAL varied from 0–36 (mean, 3.2 ± 7.8 mm), and the sum number of teeth with ABL varied from 0–6 (mean, 3.2 ± 2.3 mm). Baseline characteristics by alignment and irregularity status of the study sample are given in Tables 2.1–2.4.

The Longitudinal Association Between Maxillary Incisor Malalignment and Irregularity with Periodontal Disease Outcomes

Repeated-measure fixed/mixed effects models of the longitudinal association between periodontal disease outcomes (i.e., sum of the maximum PD, CAL, and sum of the number of teeth with ABL) and maxillary incisor alignment and irregularity status are summarized in Tables 2.5–2.8**.** After controlling for related covariates, compared to the ideal alignment, the results of the multivariate analysis showed that maxillary anterior arches with incisor crowding and spacing had a significantly greater mean sum of the maximum anterior PD (β = 0.70, 95% CI = 0.20-1.21; and β = 0.49, 95% CI = 0.06-0.91, respectively) (Table 2.5**)**. When using maxillary anterior incisor alignment as a predictor, no other significant association occurred (Table 2.6). After controlling for other confounders, compared to the no/mild incisor irregularity status, severe incisor irregularity in the maxillary arch was significantly associated with a greater anterior sum of maximum CAL (β = 2.10, 95% CI = 0.60- 3.59) (Table 2.8**)**. Maxillary anterior incisor irregularity was not significantly associated with the sum of the maximum PD or the sum of the number of teeth with ABL (Table 2.7).

The Longitudinal Association Between Mandibular Incisor Malalignment and Irregularity with Periodontal Disease Outcomes

For the analysis of the association between periodontal disease outcomes (i.e., sum of the maximum PD, CAL, and sum of the number of teeth with ABL) and mandibular incisor alignment and irregularity status, the fixed/mixed effects models are given in Tables 2.9–2.12**.** In general, the association between periodontal disease outcomes was more distinct in the mandibular arch than in the maxillary arch. After controlling for other confounders, compared to ideal alignment, mild incisor crowding in the mandibular arch was significantly associated with a greater anterior sum of the maximum PD (β = 0.47, 95% CI = 0.01-0.93) **(**Table 2.9**)**. Moderate to severe incisor crowding in the mandibular arch did not show a significant association with the anterior sum of the maximum PD (β = 0.47, 95% CI = -0.02 to 0.96) **(**Table 2.9**)**. Multivariate analysis controlling for other confounders showed that mild and moderate to severe incisor crowding in the mandibular arch had a significant positive association with the sum of the number of teeth with ABL, compared to ideal alignment (β = 0.45, 95% CI = 0.08-0.82; and β = 0.45, 95% CI = 0.13-0.83, respectively) **(**Table 2.9**)**. In addition, adjusted fixed/mixed effects models indicated that moderate to severe incisor crowding in the mandibular arch was significantly associated with a greater sum of maximum CAL (

β = 2.12, 95% CI = 0.46-3.77) (Table 2.10). When analyzing incisor irregularity in the mandibular arch, compared to no to mild incisor irregularity, the adjusted model showed that severe incisor irregularity was significantly associated with a greater anterior sum of the maximum PD (β = 0.94, 95% CI = 0.50-1.38) (Table 2.11). The adjusted fixed/mixed effects ABL model in the anterior mandibular arch also indicated that, compared to no to mild incisor irregularity, moderate incisor irregularity had a significantly higher sum number of teeth with ABL (β = 0.34, 95% CI = 0.06 – 0.62) (Table 2.11). After controlling for other confounders, moderate and severe incisor irregularity in the mandibular arch was significantly associated with a greater anterior sum of maximum CAL (β = 1.54, 95% CI = 0.31 – 2.77; and β = 2.30, 95% CI = 0.79 – 3.81, respectively) (Table 2.12).

DISCUSSION

To the best of our knowledge, this longitudinal study is the first to rigorously test the association between incisor malalignment and irregularity with per arch anterior-specific periodontal disease outcomes (i.e., anterior sum of the maximum PD, CAL, and sum number of teeth with ABL). Periodontal disease is a localized disease (Beck JD and Slade GD 1995) and the occurrence of malalignment or irregularity is greater in the anterior area (Staufer and Landmesser 2004). Many studies have accounted for these features by attempting to test the association between incisor malalignment or irregularity with several periodontal disease outcomes using an arch-specific analysis, but they often used invalid or unreliable methods to measure incisor malalignment and irregularity (Poulton and Aaronson 1961; Buckley 1972; Ainamo 1972; Geiger et al. 1974; Ingervall et al. 1977; Silness and Roynstrand 1985; Helm and Petersen 1989b; Jensen and Solow 1989; Staufer and Landmesser 2004; Ngom et al. 2006; Abu Alhaija and Al-Wahadni 2006). Some investigators even used composite measures that combine incisor malalignment and irregularity into one index, which may introduce misclassification bias resulting from existing differences between malalignment and irregularity from a theoretical and clinical prospective (Ainamo 1972; Staufer and Landmesser 2004). Furthermore, the definitions of periodontal disease were often ambiguous and invalid, thereby hindering the ability to compare our results with previous work.

The Longitudinal Association Between Maxillary Incisor Malalignment and Irregularity with Periodontal Disease Outcomes

This study found that maxillary anterior spacing was associated with a significant increase in the PD in the anterior maxillary arch, which is in agreement with one cross-sectional study (Jernberg et al. 1983). When considering maxillary crowding, our study is the first valid demonstration that maxillary anterior crowding is significantly associated with a larger PD. These results can be explained by greater food impaction with spacing and by plaque accumulation in crowded segments (Jernberg et al. 1983; Iiellgrcn 1956). The likelihood of primary or secondary occlusal trauma with flared anterior teeth in instances of spacing or crowding is another explanation (Jernberg, et al. 1983; Greenstein et al. 2008). In addition, the maxillary anterior teeth have large roots and a distinct cross-sectional shape to withstand off-axis loading that may increase destructive lateral forces on their supporting periodontal structures (Misch 2008). The CAL and alveolar bone loss in the anterior maxillary area showed greater statistical variability and no significant association with incisor spacing or crowding. This is primarily because of the inability to account for alveolar bone loss in millimeters and a loss of 12.5% (50/400) of the sample size in cases of CAL. Three other cross-sectional studies and one short longitudinal study examined the association between maxillary incisor irregularity and periodontal disease outcomes (Ingervall et al. 1977; Silness and Roynstrand 1985; Helm and Petersen 1989b; Ngom et al. 2006). The well-accepted definition of incisor irregularity was introduced earlier in 1975 by Little (Little 1975), although none of the studies (Ingervall et al. 1977; Silness and Roynstrand 1985; Helm and Petersen 1989b; Ngom et al. 2006) used a singular validated and reliable method to account for irregularity. Of these, only one study found a significant relationship between the numbers of non-aligned proximal surfaces in the anterior segment and the frequency of PD on all tooth surfaces. Our results were similar in showing a positive relationship, but it did not reach statistical significance. For reasons related to methodological dissimilarity in PD definition, the irregularity measurement, and the present rigorous statistical testing in our study, these differences were generally observed. Furthermore, the finding of no significant association between ABL and irregularity in the maxillary anterior area was in agreement with another longitudinal study (Ingervall et al. 1977). In our study, we found a significant association between CAL and maxillary incisor irregularity, which is in disagreement with one study (Ngom et al. 2006). This finding is also attributable to differences in methodological design and the appropriateness of definitions. According to the latest task force report on periodontal disease classification ("American Academy of Periodontology Task Force Report on the Update to the 1999 Classification of Periodontal Diseases and Conditions" 2015), when patients show the phenomenon in which only CAL is associated with maxillary incisor irregularity (i.e., not PD or ABL), this factor should be attributed to gingival recession only and the periodontal health condition is otherwise healthy with the presence of reduced periodontium. Although incomparable to our analysis, it is also important to note that one cross-sectional study (Ainamo 1972) found a significant positive association between the a composite malalignment index (i.e., invalid) and the mean CAL scores in the maxillary anterior segments.

The Longitudinal Association Between Mandibular Incisor Malalignment and Irregularity with Periodontal Disease Outcomes

Our sample of participants exhibited much more distinct localized anterior periodontal disease in association with malalignment in the mandibular incisor area. This finding has several reasons: (1) our sample presented with much more severe crowding and irregularity in the mandibular incisors; (2) the bone plate is thinnest in this area, particularly in the labial mandibular incisors (Clerehugh et al. 2009); (3) in this area, thin bone is often manifested as incomplete bony coverage (i.e., fenestration and dehiscence) (Clerehugh et al. 2009); (4) higher prevalence of root proximity was previously noted in the lower incisors (Artun et al. 1987; Heins et al. 1988), which is a confirmed local risk factor for periodontal disease progression in the same data source [i.e., the DLS data (Kim et al. 2008)]; and (5) the location of the incisor mandibular teeth opposing the opening of salivary gland ducts may increase local inflammatory responses (Mandel 1995). We report the first significant positive association between mandibular incisor crowding (mild or moderate/severe) and PD, ABL, and CAL. Other studies investigating these associations were cross-sectional in design, used composite periodontal disease indices (i.e., invalid), and questionably acceptable crowding measurements (Poulton and Aaronson 1961; Buckley 1972; Geiger et al. 1974). Other than a short longitudinal study (Ingervall et al. 1977) that had several limitations, including using a very short follow-up period, small sample size (n = 50), lack of accounting for attachment loss, and use of neither reliable nor validated methods in measuring malalignment, this study is the first to demonstrate a significant positive association between mandibular incisor irregularity (moderate or severe) and PD, ABL, and CAL. With regards to PD in particular, three cross-sectional studies (Silness and Roynstrand 1985; Staufer and Landmesser 2004; Ngom et al. 2006) were in agreement with our significant positive findings, whereas two studies (Helm and Petersen 1989b; Abu Alhaija and Al-Wahadni 2006) were in disagreement. Furthermore, one cross-sectional study (Jensen and Solow 1989) examining the association between ABL and mandibular incisor irregularity reported similar significant positive relationship, whereas another cross-sectional study that recruited children did not (Abu Alhaija and Al-Wahadni 2006). Compared to our results, the two cross-sectional studies used CAL as an outcome measure and reported conflicting results whereas one study (Ngom et al. 2006) revealed a significant positive association with mandibular incisor irregularity in adults; however, another study (Abu Alhaija and Al-Wahadni 2006) reported no significant association in children. In comparison to our analysis, one cross-sectional study (Ainamo 1972) found a significant positive association between a composite malalignment index (i.e., invalid) and the mean CAL scores in the mandibular anterior segments. Likewise, one cross-sectional study (Staufer and Landmesser 2004) found a significant positive association between a composite malalignment index (i. e., invalid index) and mean PD scores in the mandibular anterior segments.

The strengths of our study include the use of a well-designed longitudinal study with a large number of recruited participants with a long period of follow up, and the use of a rigorous statistical testing (i.e., adjusted fixed/mixed effect models). However, this study has several important limitations. The generalizability of the results of this cohort study is limited because the recruited participants were only confined to Caucasian males; thereby, limiting the ability to examine the effect of sex across the hypothesis. Only maxillary and mandibular anterior teeth were available for our analysis. This factor was because of the incomplete set of posterior teeth at baseline cast records. In both arches the severity of malalignment was not great, which restricted our ability to observe the effect of severe malalignment (>5 mm) on periodontal disease outcomes. Furthermore, the first three triennial examinations (1971–1981) did not include information regarding CAL. This reduced the sample size and statistical variability that may potentially underestimate the reported association between CAL and different predictors of malalignment. The CAL was only measured in the proximal surfaces where the least tissue loss was clinically observed, which added to greater underestimation. Furthermore, underestimation is predicted in periodontal disease outcomes because our participants were limited to those who attended at least three triennial follow-ups, indicating that they had a greater interest in their oral health. In this study, ABL was reported as a percentile variable rather than as a millimeter change. This factor did not allow us to see much change in the ABL variable, compared to the millimeter changes in PD and CAL.

In conclusion, this longitudinal study was the first to provide evidence that certain malalignment traits in the incisor area in the maxillary arch and mandibular arch are a risk factor in periodontal disease progression. General dentists should inform their patients about the impact of incisor malalignment on periodontal health, and provide appropriate orthodontic referrals. This study should also have a future impact on the practice of orthodontics from providing esthetic and functional treatments to engaging in preventive treatments by alleviating incisor malalignment.

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Table 2.1. Distribution of maxillary incisor alignment by selected characteristics for study participants at baseline (n = 400)

Characteristics	**Maxillary Incisor Alignment**		
	Spacing (n = 192)	**Ideal Alignment (n = 112)**	**Crowding (n = 91)**
Age (y), mean ± SD	49.4 ± 7.6	49.4 ± 7.3	49.4 ± 7.2
Number of teeth remaining, mean ± SD [a]	24.1 ± 2.9	24.9 ± 2.9	25.1 ± 2.2
Number of medications used, mean ± SD	1.5 ± 1.4	1.5 ± 2.9	1.6 ± 1.5
Income (%) [b]			
≤$14,999	34.6	31.3	37.9
$15,000–$24,999	48.1	47.8	49.4
≥$25,000	17.3	20.9	12.6
Educational level (%) [b]			
High school or some college	30.7	22.2	24.2
College graduate	69.3	77.8	75.8
Smoking status (%)			
Nonsmoker	68.8	69.2	69.2
Smoker	31.2	30.8	30.8
Flossing frequency (%)			
Never	44.3	41.9	42.9
At least once monthly	55.7	58.1	57.1
Brushing frequency (%) [b]			
Once a week or less	32.5	36.8	53.9
Twice a week of more	67.5	63.2	46.1
Saliva (%) [b]			
Limited	19.8	11.1	26.4
Copious	80.2	88.9	73.6
Prophylaxis in past year (%)	66.2	66.7	70.3
Gum treatment in the past year (%)	6.8	6.8	6.6
Maxillary anterior plaque index, mean ± SD	7.6 ± 3.7	7.4 ± 3.5	7.6 ± 3.5
Maxillary anterior calculus index, mean ± SD [a]	3.8 ± 4.4	3.2 ± 4.0	4.0 ± 4.0
Maxillary anterior mobility, mean ± SD [a]	0.8 ± 2.0	0.6 ± 1.5	0.4 ± 1.2
Maxillary anterior sum of maximum pocket depth, mean ± SD [a]	2.1 ± 3.9	1.0 ± 2.0	2.2 ± 3.7
Maxillary anterior sum of maximum clinical attachment loss, mean ± SD [c]	2.3 ± 6.2	2.0 ± 4.8	2.4 ± 5.2
Maxillary anterior sum number of teeth with bone loss, mean ± SD [a]	2.0 ± 2..2	1.8 ± 2.1	2.0 ± 2.3

[a] Difference between the levels of alignment, $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of alignment, $P < 0.05$, based on the Chi-square statistic.

[c] Based only on data obtained from 1981 onward (n = 350).

SD, standard deviation.

Table 2.2. Distribution of maxillary incisor irregularity by selected characteristics of the study participants at baseline (n = 400)

Characteristics	**Maxillary Incisor Irregularity**		
	No/Mild (n = 272)	**Moderate (n = 81)**	**Severe (n = 47)**
Age (y), mean ± SD [a]	49.3 ± 7.8	50.3 ± 7.0	48.2 ± 8.1
Number of teeth remaining, mean ± SD	24.5 ± 2.7	24.6 ± 2.9	24.6 ± 2.9
Number of medications used, mean ± SD [a]	1.5 ± 1.5	1.6 ± 1.5	1.6 ± 1.5
Income (%) [b]			
≤$14,999	35.9	31.7	30.2
$15,000–$24,999	46.4	58.2	41.9
≥$25,000	17.7	10.1	27.9
Educational level (%) [b]			
High school or some college	26.1	25.9	31.9
College graduate	73.9	74.1	68.1
Smoking status (%)			
Nonsmoker	68.8	70.4	68.1
Smoker	31.3	29.4	31.9
Flossing frequency (%) [b]			
Never	43.8	38.3	48.9
At least once\month	56.2	61.7	51.1
Brushing frequency (%)			
Once a week or less	38.4	37.0	42.6
Twice a week of more	61.6	63.0	57.4
Saliva (%) [b]			
Limited	17.6	22.2	19.1
Copious	82.4	77.8	80.9
Prophylaxis in past year (%) [b]	65.8	66.7	76.7
Gum treatment in the past year (%) [b]	8.1	1.2	8.5
Maxillary anterior plaque index, *mean ± SD* [a]	7.3 ±3.6	7.7 ± 3.5	8.3 ± 3.4
Maxillary anterior calculus index, *mean ± SD* [a]	3.4 ± 4.2	4.5 ± 4.6	3.5 ± 3.2
Maxillary anterior mobility, *mean ± SD*	0.7 ± 1.7	0.6 ± 1.4	0.6 ± 1.9
Maxillary anterior sum of maximum pocket depth, *mean ± SD* [a]	1.7 ± 3.1	2.1 ± 4.2	2.0 ± 3.4
Maxillary anterior sum of maximum clinical attachment loss, *mean ± SD* [a, c]	2.1 ± 5.5	2.2 ± 4.6	3.4 ± 5.5
Maxillary anterior sum number of teeth with bone loss, *mean ± SD*	1.9 ± 2.2	2.0 ± 2.1	2.1 ± 2.3

[a] Difference between levels of irregularity, $P < 0.05$, analysis of variance.

[b] Differences between levels of irregularity, $P < .05$, Chi-Square statistic.

[c] Only taken at 1981 and forward (n = 350).

SD, standard deviation

Table 2.3. Distribution of mandibular incisor alignment by selected characteristics of the study participants at baseline (n = 408)

Characteristics	**Mandibular Incisor Alignment**			
	Spacing (n = 96)	**Ideal Alignment (n = 76)**	**Mild Crowding (n = 135)**	**Moderate/Severe Crowding (n = 101)**
Age (y), mean ± SD [a]	49.5 ± 7.5	47.9 ± 7.8	50.0 ± 8.0	50.0 ± 7.3
Number of teeth remaining, mean ± SD [a]	24.2 ± 3.1	24.6 ± 3.0	24.4 ± 2.7	24.9 ± 2.6
Number of medications used, mean ± SD [a]	1.7 ± 1.7	1.5 ± 1.4	1.3 ± 1.4	1.6 ± 1.5
Income (%) [b]				
≤$14,999	34.4	29.7	37.9	32.6
$15,000–$24,999	50.0	47.3	47.7	48.0
≥$25,000	15.6	23.0	14.4	19.4
Educational level (%) [b]				
High school or some college	29.2	27.6	28.9	19.8
College graduate	70.8	72.4	71.1	80.2
Smoking status (%) [b]				
Nonsmoker	63.5	64.5	72.6	72.3
Smoker	36.5	35.5	27.4	27.7
Flossing frequency (%) [b]				
Never	51.0	39.5	45.9	36.6
At least once\month	49.0	60.5	54.1	63.4
Brushing frequency (%) [b]				
Once a week or less	37.5	38.2	35.1	41.6
Twice a week of more	62.5	61.8	64.9	58.4
Saliva (%) [b]				
Limited	25.0	13.2	13.3	24.8
Copious	75.0	86.8	86.7	75.2
Prophylaxis in past year (%) [b]	72.9	61.8	68.9	65.4
Gum treatment in the past year (%) [b]	7.3	2.6	8.9	6.9
Mandibular anterior plaque index, mean ± SD [a]	10.8 ± 3.3	11.3 ± 3.4	11.9 ± 3.5	12.4 ± 3.2
Mandibular anterior calculus index, mean ± SD [a]	8.7 ± 4.7	9.5 ± 5.0	9.9 ± 4.3	10.1 ± 4.1
Mandibular anterior mobility, mean ± SD [a]	0.5 ± 1.7	0.1 ± 0.6	0.3 ± 1.2	0.1 ± 0.6
Mandibular anterior sum of maximum pocket depth, mean ± SD [a]	1.4 ± 3.2	1.1 ± 2.3	1.5 ± 2.9	1.5 ± 2.5
Mandibular anterior sum of maximum clinical attachment loss, mean ± SD [a, c]	2.0 ± 6.1	3.4 ± 8.5	3.2 ± 6.2	5.0 ± 8.9
Mandibular anterior sum number of teeth with bone loss, mean ± SD [a]	3.2 ± 2.4	2.8 ± 2.3	3.4 ± 2.2	3.5 ± 2.3

[a] Difference between the levels of alignment, $P < 0.05$, based on analysis of variance.
[b] Difference between the levels of alignment, $P < 0.05$, based on the Chi-square statistic.
[c] Based only on data obtained from 1981 onward (n = 358).

SD, standard deviation.

Table 2.4. Distribution of mandibular anterior irregularity by selected characteristics of the study participants at baseline (n = 408)

Characteristics	**Mandibular Incisor Irregularity**		
	No/Mild (n = 205)	**Moderate (n = 132)**	**Severe (n = 71)**
Age (y), mean ± SD [a]	50.7 ± 7.7	50.5 ± 7.7	50.0 ± 7.5
Number of teeth remaining, mean ± SD	24.4 ± 2.8	24.5 ± 3.1	24.7 ± 2.8
Number of medications used, mean ± SD	1.5 ± 1.5	1.5 ± 1.4	1.5 ± 1.5
Income (%) [b]			
≤$14,999	30.9	38.7	36.9
$15,000 – $24,999	49.3	50.8	48.1
= > $25,000	19.9	10.5	15
Educational level (%) [b]			
High school or some college	29.8	25.0	23.5
College graduate	70.2	75.0	76.5
Smoking status (%) [b]			
Nonsmoker	65.4	70.5	73.0
Smoker	34.6	29.5	27.0
Flossing frequency (%) [b]			
Never	47.3	40.2	42.2
At least once\month	52.7	59.8	57.8
Brushing frequency (%)			
Once a week or less	36.8	39.4	38.8
Twice a week of more	63.7	60.6	61.2
Saliva (%) [b]			
Limited	18.5	17.4	19.4
Copious	81.5	82.6	80.6
Prophylaxis in past year (%) [b]	65.4	75.8	69.9
Gum treatment in the past year (%)	6.8	7.6	7.1
Mandibular anterior plaque index, mean ± SD [a]	11.1 ± 3.7	12.1 ± 3.2	12.1 ± 3.2
Mandibular anterior calculus index, mean ± SD [a]	9.3 ± 4.7	9.6 ± 4.5	9.8 ± 4.3
Mandibular anterior mobility, mean ± SD [a]	0.2 ± 1.1	0.4 ± 1.3	0.3 ± 1.3
Mandibular anterior sum of maximum pocket depth, mean ± SD [a]	1.2 ± 2.4	1.4 ± 2.9	1.5 ± 2.9
Mandibular anterior sum of maximum clinical attachment loss, *mean ± SD* [a, c]	2.5 ± 7.0	3.0 ± 7.1	3.7 ± 7.8
Mandibular anterior sum number of teeth with bone loss, *mean ± SD* [a]	3.0 ± 2.3	3.6 ± 2.1	3.4 ± 2.3

[a] Difference between levels of irregularity, $P < 0.05$, based on analysis of variance.

[b] Differences between levels of irregularity, $P < 0.05$, based only on the Chi-square statistic.

[c] Based only on data obtained at the fifth cycle onward (n = 358).

SD, standard deviation.

Table 2.5. Unadjusted and adjusted mixed/fixed effects estimates and 95% confidence intervals of the association between <u>maxillary anterior incisor alignment</u> and anterior sum of maximum pocket depth, and the number of teeth with alveolar bone loss (n = 400)

Periodontal Disease Outcomes	**Alignment Status Beta Estimate (95% CI)**						
	Continuous Variables		**Categorical Variables**				
			Spacing (n = 192)		**Ideal (n = 112)**	**Crowding (n = 91)**	
	Unadjusted	Adjusted ^{a}	Unadjusted	Adjusted ^{a}	Reference	Unadjusted	Adjusted ^{a}
Anterior maxillary sum of the maximum pocket depth	-0.02 (-0.12 to 0.74)	-0.06 (-0.14 to 0.02)	0.84* (0.34-1.34)	0.49* (0.06-0.91)	-	0.98 * (0.39-1.57)	0.70 * (0.20-1.21)
Anterior maxillary sum number of teeth with bone loss	-0.02 (-0.09 to 0.05)	-0.01 (-0.07 to 0.05)	0.01 (-0.34 – 0.36)	-0.00 (-0.31 – 0.30)	-	0.15 (-0.27 to 0.57)	0.11 (-0.25 to 0.48)

* $P < 0.05$

[a] Model adjusted for age, maxillary anterior plaque score, maxillary anterior calculus score, maxillary anterior mobility score, college education (yes/no), smoking (yes/no), flossing (never/ever), brushing (≤ 1 times a day/ ≥2 times a day), prophylaxis treatment in the last year (yes/no), gum treatment in the last year (yes/no), income (low: ≤$14,999; middle: $15,000–$24,999; high: ≥$25,000), and number of remaining teeth in the anterior arch.

CI, confidence interval.

Table 2.6. Unadjusted and adjusted mixed/fixed effects estimates and 95% confidence intervals (95% CI) of the association between <u>maxillary anterior incisor alignment</u> and anterior sum of maximum clinical attachment loss (n = 350)

Periodontal Disease Outcome	**Alignment Status Beta Estimate (95% CI)**						
	Continuous Variables		**Categorical Variables**				
			Spacing (n = 167)		**Ideal (n = 101)**	**Crowding (n = 82)**	
	Unadjusted	Adjusted^a	Unadjusted	Adjusted^a	Reference	Unadjusted	Adjusted^a
Anterior maxillary sum of maximum clinical attachment loss	-0.13 (-0.40 – 0.13)	-0.18 (-0.39 – 0.29)	0.39 (-1.02 – 1.79)	-0.13 (-1.35 – 1.10)	-	0.95 (-0.70 – 2.60)	0.49 (-0.95 – 1.94)

* $P < 0.05$

[a] Model adjusted for age, maxillary anterior plaque score, maxillary anterior calculus score, maxillary anterior mobility score, college education (yes/no), smoking (yes/no), flossing (never, ever), brushing (≤1 times a day/≥2 times a day), prophylaxis treatment in the last year (yes/no), gum treatment in the last year (yes/no), income (low: ≤$14,999; middle: $15,000–$24,999; high: ≥$25,000), and number of remaining teeth in the anterior arch.

CI, confidence interval.

Table 2.7. Unadjusted and adjusted mixed/fixed effects estimates and 95% confidence intervals of the association between maxillary anterior incisor irregularity and anterior sum of the maximum pocket depth, and number of teeth with alveolar bone loss (n = 400)

Periodontal Disease Outcomes	**Irregularity Status Beta Estimate (95% CI)**						
	Continuous Variables		**Categorical Variables**				
			No/Mild (n = 272)	**Moderate (n = 81)**		**Severe (n = 47)**	
	Unadjusted	Adjusted [a]	Reference	Unadjusted	Adjusted [a]	Unadjusted	Adjusted [a]
Anterior maxillary sum of the maximum pocket depth	0.03 (-0.07 to 0.12)	0.02 (-0.07 to 0.10)	-	0.25 (-0.29 to 0.79)	0.06 (-0.39 to 0.52)	0.13 (-0.50 to 0.84)	0.21 (-0.37 to 0.79)
Anterior maxillary sum number of teeth with bone loss	0.03 (-0.05 to 0.08)	0.01 (-0.05 to 0.06)	-	0.17 (-0.21 to 0.54)	0.07 (-0.25 to 0.41)	0.20 (-0.28 to 0.67)	0.14 (-0.27 to 0.56)

$^{*}P < 0.05$

[a] Model adjusted for age, maxillary anterior plaque score, maxillary anterior calculus score, maxillary anterior mobility score, college education (yes/no), smoking (yes/no), flossing (never/ever), brushing (≤1 times a day/≥2 times a day), prophylaxis treatment in the last year (yes/no), gum treatment in the last year (yes/no), income (low: ≤$14,999; middle: $15,000–$24,999; high: ≥$25,000), and number of remaining teeth in the anterior arch.

CI, confidence interval.

Table 2.8. Unadjusted and adjusted mixed/fixed effects estimates and 95% confidence intervals of the association between maxillary anterior incisor irregularity and anterior sum of maximum clinical attachment loss (n = 350)

Periodontal Disease Outcome	**Irregularity status beta estimate (95% CI)**						
	Continuous		**Categorical**				
			No/Mild (n = 236)	**Moderate (n = 73)**		**Severe (n = 41)**	
	Unadjusted	Adjusted [a]	Reference	Unadjusted	Adjusted [a]	Unadjusted	Adjusted [a]
Anterior maxillary sum of maximum clinical attachment loss	0.18 (-0.08 to 0.44)	0.17 (-0.02 to 0.38)	-	-0.26 (-1.70 to 1.18)	-0.42 (-1.59 to 0.74)	1.86 * (0.06 to 3.65)	2.10 * (0.60 to 3.59)

$*P < 0.05$

[a] Model adjusted for age, maxillary anterior plaque score, maxillary anterior calculus score, maxillary anterior mobility score, college education (yes/no), smoking (yes/no), flossing (never, ever), brushing (≤1 times a day/≥2 times a day), prophylaxis treatment in the last year (yes/no), gum treatment in the last year (yes/no), income (low: ≤$14,999; middle: $15,000–$24,999; high: ≥$25,000), and number of remaining teeth in the anterior arch.

CI, confidence interval.

Table 2.9. Unadjusted and adjusted mixed/fixed effects estimates and 95% confidence intervals of the association between mandibular anterior incisor alignment and anterior sum of the maximum pocket depth, and number of teeth with alveolar bone loss (n = 408).

Periodontal Disease Outcomes	**Alignment status beta estimate (95% CI)**								
	Continuous Variables		**Categorical Variables**						
			Spacing (n = 96)		**Ideal (n = 76)**	**Mild Crowding (n = 135)**		**Moderate/Severe Crowding (n = 101)**	
	Unadjusted	Adjusted [a]	Unadjusted	Adjusted [a]	Reference	Unadjusted	Adjusted [a]	Unadjusted	Adjusted [a]
Anterior mandibular sum of the maximum pocket depth	-0.07 (-0.15 to 0.01)	-0.06 (-0.13 to 0.01)	0.12 (-0.47 to 0.71)	-0.08 (-0.59 to 0.42)	-	0.60 * (0.05 to 1.14)	0.47 * (0.01 to 0.93)	0.70 * (0.08 to 1.23)	0.47 (-0.02 to 0.96)
Anterior mandibular sum of the number of teeth with bone loss	0.01 (-0.05 to 0.07)	-0.01 (-0.06 to 0.04)	0.21 (-0.20 to 0.63)	0.24 (-0.14– 0.63)	-	0.46 * (0.08 to 0.85)	0.45 * (0.13 to 0.83)	0.36 (-0.05 to 0.77)	0.45 * (0.08 to 0.82)

*$P < 0.05$

[a] Model adjusted for age, mandibular anterior plaque score, mandibular anterior calculus score, mandibular anterior mobility score, college education (yes/no), smoking (yes/no), flossing (never/ever), brushing (≤1 times a day/≥2 times a day), prophylaxis treatment in the last year (yes/no), gum treatment in the last year (yes/no), income (low: ≤$14,999; middle: $15,000–$24,999; high: ≥$25,000), and number of remaining teeth in the anterior arch.

CI, confidence interval.

Table 2.10. Unadjusted and adjusted mixed/fixed effects estimates and 95% confidence intervals of the association between mandibular anterior incisor alignment and anterior sum of maximum clinical attachment loss (n = 358)

Ideal (n = 65) Reference 1.00	**Alignment Status Beta Estimate (95% CI)**								
	Continuous Variables		**Categorical Variables**						
			Spacing (n = 82)		**Ideal (n = 65)**	**Mild Crowding (n = 123)**		**Moderate/Severe Crowding (n = 88)**	
	Unadjusted	Adjusted [a]	Reference	Adjusted [a]	Reference	Unadjusted	Adjusted [a]	Unadjusted	Adjusted [a]
Anterior mandibular sum of maximum clinical attachment loss	-0.19 (-0.52 to 0.14)	-0.20 (-0.4 to 0.02)	0.22 (-2.22 to 2.67)	-0.10 (-1.82 to 1.61)	-	0.44 (-1.80 to 2.69)	0.58 (-0.97 to 2.11)	2.38 * (-0.02 to 4.77)	2.12* (0.46 to 3.77)

*$P < 0.05$.

[a] Model adjusted for age, mandibular anterior plaque score, mandibular anterior calculus score, mandibular anterior mobility score, college education (yes/no), smoking (yes/no), flossing (never/ever), brushing (≤1 times a day/≥2 times a day), prophylaxis treatment in the last year (yes/no), gum treatment in the last year (yes/no), income (low: ≤$14,999; middle: $15,000–$24,999; high: ≥$25,000), and number of remaining teeth in the anterior arch.

CI, confidence interval.

Table 2.11. Unadjusted and adjusted mixed/fixed effects estimates and 95% confidence intervals of the association between mandibular anterior incisor irregularity and anterior sum of the maximum pocket depth and number of teeth with alveolar bone loss (n = 400)

Periodontal Disease Outcomes	**Irregularity status beta estimate (95% CI)**						
	Continuous		**Categorical**				
			No/Mild (n = 205)	**Moderate (n = 132)**		**Severe (n = 71)**	
	Unadjusted	Adjusted[a]	Reference	Unadjusted	Adjusted [a]	Unadjusted	Adjusted [a]
Anterior mandibular sum of maximum pocket depth	0.10 * (0.02 – 0.19)	0.08 * (0.01 – 0.15)	-	0.02 (-0.40 to 0.44)	-0.04 (-0.40– 0.32)	0.97 * (0.45 to 1.49)	0.10* (0.02 to 0.19)
Anterior mandibular sum number of teeth with bone loss	0.05 (-0.01 – 0.11)	0.07 * (0.01 – 0.12)	-	0.32 * (0.02 to 0.63)	0.34 * (0.06 to 0.62)	0.07 (-0.30 to 0.44)	0.05 (-0.01 to 0.11)

* $P < 0.05$.

[a] Model adjusted for age, maxillary anterior plaque score, maxillary anterior calculus score, maxillary anterior mobility score, college education (yes/no), smoking (yes/no), flossing (never, ever), brushing (≤ 1 times a day/ ≥2 times a day), prophylaxis treatment in the last year (yes/no), gum treatment in the last year (yes/no), income (low: ≤$14,999; middle: $15,000–$24,999; high: ≥$25,000), and number of remaining teeth in the anterior arch.

CI, confidence interval.

Table 2.12. Unadjusted and adjusted mixed/fixed effects estimates and 95% confidence intervals of the association between mandibular anterior incisor irregularity and anterior sum of maximum clinical attachment loss (n = 358)

Periodontal Disease Outcome	**Irregularity status beta estimate (95% CI)**						
	Continuous Variables		**Categorical Variables**				
			No/Mild (n = 179)	**Moderate (n = 119)**		**Severe (n = 60)**	
	Unadjusted	Adjusted[a]	Reference	Unadjusted	Adjusted [a]	Unadjusted	Adjusted [a]
Anterior mandibular sum of maximum clinical attachment loss	1.13 (0.32 to 2.34) *	1.20 (0.49 to 1.90) *	-	1.40 (-0.35 to 3.16)	1.54 (0.31 to 2.77) *	2.82 * (0.65 to 5.00)	2.30 (0.79 to 3.81) *

*$P < 0.05$

[a] Model adjusted for age, maxillary anterior plaque score, maxillary anterior calculus score, maxillary anterior mobility score, college education (yes/no), smoking (yes/no), flossing (never/ever), brushing (≤1 times a day/≥2 times a day), prophylaxis treatment in the last year (yes/no), gum treatment in the last year (yes/no), income (low: ≤$14,999; middle: $15,000–$24,999; high: ≥$25,000), and number of remaining teeth in the anterior arch.

CI, confidence interval.

JOURNAL ARTICLE TWO

Incisor Malalignment and the Risk for Tooth Loss

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ABSTRACT

Several epidemiological studies report a significant positive association between malalignment traits and periodontal disease and dental caries, the primary causes of tooth loss. The purpose of this longitudinal study was to assess if maxillary and mandibular incisor malalignment is predictive for all-cause tooth loss. The Veterans Affairs Dental Longitudinal Study (DLS) included 400 maxillary casts and 408 mandibular casts with a complete set of anterior sextants from participants in their late fifth decade. As part of a triennial dental examination by calibrated periodontists, the tooth level record of all-cause tooth loss (i.e., dental caries, periodontal disease, trauma, and patient–dentist relationship-related causes) was recorded for each participant. Per arch incisor malalignment was defined by two methods: the anterior tooth size–arch length discrepancy (aTSALD) index and Little's Irregularity Index (LII). Just over 35 years of follow up was available for analysis. In the DLS data, longer survival times were more probable in both anterior arches, indicating that the risk of tooth loss was initially small but increased with time. Adjusted per arch tooth level Cox proportional hazard models were used to compute the hazard ratios (HRs) and 95% confidence intervals (95% CI) of the association between malalignment traits and all-cause tooth loss. Maxillary segments with spacing had a 401% significantly greater hazard (HR = 5.01, 95% CI = 1.16-21.64) of all-cause tooth loss, compared to the ideal alignment (i.e., the reference group). However, other malalignment traits were not statistically significantly related to tooth loss. Incisor malalignment is potentially predictive of all-cause tooth loss. These data suggest that incisor malalignment may intensify existing poor oral health conditions that lead to tooth loss.

Keywords: tooth loss, malalignment, irregularity, crowding, cohort study, longitudinal study, aging

INTRODUCTION

Partial or complete tooth loss is the dental equivalent of death (Burt and Eklund 2005). Tooth loss is linked to inferior quality of life and diminished general health (Marshall et al. 2002). In the United States, the National Health and Nutrition Examination Survey data (NHANES 2011–2012) reported that just over one-half (51.8%) of the adult population has lost at least one tooth in adulthood (i.e., 20–64 years old), and 19% of the elderly (i.e., 65 years and older) had complete tooth loss. Epidemiological studies (Ainamo et al. 1984; Bouma et al. 1985; Cahenet al. 1985; Baelum and Fejerskov 1986; Kay and Blinkhorn 1986; Bailit et al. 1987; Bouma et al. 1987; Agerholm and Sidi 1988; Manjiet al. 1988; Chauncey et al. 1989; Luan et al. 1989; Niessen and Weyant 1989; Corbet and Davies 1991; Stephens et al. 1991; Mosha and Lema 1991; Eckerbom et al. 1992) across different populations established that dental caries is primarily the cause of tooth loss across most ages, with the exception of people over 80 years old (Warren et al. 2002). However, additional epidemiological studies noted that periodontal disease in other populations was the leading cause for tooth loss (Murray, et al. 1996; Phipps and Stevens 1995). Dental plaque occurs in the pathway and pathogeneses of dental caries and periodontal disease (Loesche 1996). Dental caries is a multifactorial disease that primarily occurs because of bacterial adherence to dental plaque by which bacterial acid production permanently affects the solubility of tooth mineralization, whereas periodontal disease occurs as a result of an inflammatory response to plaque (Loesche 1996). One contributing factor for increased plaque accumulation is the malalignment of teeth (Addy et al. 1988; Gábris et al. 2006). This finding results primarily from the effect of teeth malalignment on interfering with normal dental contacts that sustain the proper teeth embrasures and self-cleansing action. To that end, malalignment has been associated with dental caries (Hixon et al. 1962; Roder and Arend 1971; Helm and Petersen 1989a; Stahl and Grabowski 2004; Buczkowska-Radlinska et al. 2012) and periodontal disease (Buckley 1972; Ainamo 1972; Silness and Roynstrand 1985; Staufer and Landmesser 2004; Ngom et al. 2006), particularly in the anterior segments (Hixon et al. 1962; Roder and Arend 1971; Buckley 1972; Ainamo 1972; Silness and Roynstrand 1985; Helm and Petersen 1989b; Staufer and Landmesser 2004; Ngom et al. 2006; Buczkowska-Radlinska et al. 2012). In the United States, 75% and 78% of the U.S. population experienced a degree of incisor maxillary malalignment and mandibular malalignment, respectively (Brunelle et al.1996). The great occurrence of incisor malalignment in the population and its effect on dental caries and periodontal disease suggests its possible association with tooth loss. Therefore, this study aimed to determine whether incisor malalignment predicts the rate of anterior tooth loss in older men.

MATERIAL AND METHODS

The data were obtained from a closed-panel Dental Longitudinal Study (DLS) of the U.S. Department of Veterans Affairs in Boston, Massachusetts. The DLS is a part of the Normative Aging Study (NAS) with 2,280 healthy male enrollees. In 1969, the DLS began examining, in parallel with the NAS, 1,231 Caucasian men who received their medical and dental care in the private sector rather than through the Veteran Affairs (VA) healthcare system (Kapur et al. 1972). By using a triennial approach (1969–2009), data collection included a comprehensive dental and medical examination by three calibrated periodontists (Edward Loftus, 1969 to 1979; Roy Feldman, 1979 to 1984; Raul Garcia, 1984 to 2009). As part of the dental examination, the tooth level record of all-cause tooth loss (i.e., dental caries, periodontal disease, trauma, and patient-dentist relationship-related causes) was recorded for each participant. In addition, the upper and lower plaster casts from alginate impressions were obtained in the first five triennial examinations (1969–1985) with the highest number of casts obtained during the second triennial examinations (1971–1976). The baseline records were accordingly set to the second triennial examinations (1971–1976). Our inclusion criteria included the following: (1) the individual had at least 3 years of follow up, (2) a complete set of anterior teeth sextants in the upper and lower arches at baseline (maxillary sextants: from 6 to 11; mandibular sextants: from 22 to 27), (3) a complete examination recorded on individual tooth status (i.e., present/absent tooth), (4) did not have previously reported orthodontic treatment, and (5) a measurable cast at baseline. By applying an arch-specific investigation, the sample size included 400 upper and 408 and lower casts. This corresponded to 2,400 upper teeth and 2,448 lower teeth. Anterior malalignment by arch (i.e., maxillary incisor malalignment, and mandibular incisor malalignment) was obtained from plaster casts by using two methods of measurement (Harris, Vaden, and Williams 1987; Little 1975). First, by using a digital caliper, the arch-specific anterior tooth size–arch length discrepancy (aTSALD) index was acquired through subtracting the incisor space available (i.e., using a flexible ruler graded in millimeters positioned on the incisor edges from the maximum point of canines distally) from the anterior space required (i.e., the sum of maximum mesiodistal widths of the anterior teeth in millimeters) (Harris, et al. 1987). The severity of dental malalignment was categorized using the index of orthodontic treatment needs (spacing: >0 mm; ideal alignment: 0 mm; mild crowding: <0 mm and ≥-2 mm; moderate to severe crowding: <-2 mm) (Brook and Shaw 1989). Because of the limited number of severe cases, modification of this classification (i.e., regrouping mild and moderate to severe into the presence of any crowding category) was used in the maxillary anterior segments. The second method of malalignment quantified for arch-specific incisor irregularity for which a digital caliper was placed parallel to the occlusal plane to measure the labiolingual linear displacement of anatomical contact points in the anterior sextants (Little 1975). The severity of incisor irregularity was modified into three categories: none to mild irregularity, ≥0 mm and <4 mm; moderate irregularity, ≥4 mm and ≤6 mm; and severe irregularity, >6 millimeters (Little 1975). To determine the intraexaminer reliability, a random sample of 50 casts were selected (just over 10% of the sample size) and measured on two occasions at 2 weeks apart. Differences in arch-specific measurements (i.e., upper incisor alignment, lower incisor alignment, upper incisor irregularity, and lower incisor irregularity) were estimated by calculating the intraclass correlation coefficient of reliability (ICC). Baseline bivariate analysis using analysis of variance (ANOVA) and chi-square test were used to identify the statistical association between baseline characteristics and arch-specific malalignment variables. Just over 35 years of follow up were available for longitudinal analysis. Per arch tooth level longitudinal analyses were adjusted for age in years, college education (yes/no), smoking (yes/no), flossing (never/ever), and brushing (≤1 times a day/≥2 times a day). Tooth level Cox proportional hazard model analysis for each arch was used to test for the association between incisor malalignment variables (i.e., upper incisor alignment, lower incisor alignment, upper incisor irregularity, and lower incisor irregularity) and tooth loss, accounting for multiple outcomes within each arch/individual. The proportional hazards assumption was checked by testing for interaction terms between the function of survival time and all predictors and covariates. Once such an interaction was significant, the interaction was kept in the model to adjust for the lack of proportionality and to stabilize the model. All statistical analyses were performed using SAS 9.4. The study was approved by the VA Boston Healthcare System, and the Institutional Review Board of Boston University (Boston, MA). All participants gave written, informed consent before entry. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies.

RESULTS

Tables 3.1–3.4 show the per arch baseline characteristics by maxillary incisor alignment, maxillary incisor irregularity, mandibular incisor alignment, and mandibular incisor irregularity, respectively. Our participants were in their late fifth decade. Maxillary segment time to tooth loss had a mean of 23.7 ± 8.4 years (range, 0–36 years), and the mandibular segment time to tooth loss similarly had a mean of 23.5 ± 8.5 years (range, 0–36 years). This indicates that longer survival times are more probable in both anterior arches, which suggested that the risk of tooth loss is initially low and increases with time. Tables 3.5 and 3.6 show the hazard ratios (HRs) from the crude and adjusted tooth level Cox survival regression for the incidence of tooth loss on malalignment variables in the anterior maxillary and mandibular segments, respectively. The HRs were adjusted for time-dependent covariates that include age in years, college education (yes/no), smoking (yes/no), flossing (never/ever), and brushing (≤1 times a day/≥2 times a day). A small number (approximately 5%) of tooth loss events occurred in the maxillary and mandibular segments, and thereby corresponded to an imprecise estimate in the adjusted models. In the maxillary segment, a lack of proportional hazard assumption was also noted between age in years and the function of survival time (β = -0.01, P = 0.02). This finding implies that in the maxillary segment, the effect of age is increased by follow-up time. To control for the lack of proportional hazard, the interaction term was kept in the Cox survival model of tooth loss incidence in the maxillary anterior segments.

Adjusted Incidence of All-Cause Tooth Loss in the Maxillary Anterior Segment

Maxillary segments with spacing had a 401% significantly greater hazard (HR = 5.01, 95% CI = 1.16-21.64) of all-cause tooth loss, compared to the ideal alignment (i.e., the reference group). It is important to note that in this model, the spacing subcategory had twice the person-time, compared to any other subcategory. Maxillary segments with crowding had 95% greater hazard (HR = 1.95, 95% CI = 0.40-9.41) of all-cause tooth loss, compared to the reference group. Maxillary segments with moderate irregularity had 70% less hazard (HR = 0.30, 95% CI = 0.07-1.23) of all-cause tooth loss, compared to no/mild irregularity (i.e., the reference group). Maxillary segments with severe irregularity had 64% less hazard (HR = 0.36, 95% CI = 0.09-1.36) of all-cause tooth loss, compared to the reference group. These inverse associations were not significant and primarily resulted from longer person-year follow-up period (approximately 3 times more) in the no/mild irregularity group.

Adjusted Incidence of All-Cause Tooth Loss in the Mandibular Anterior Segment

Mandibular segments with spacing had 60% greater hazard (HR = 1.60, 95% CI = 0.42-6.05) of all-cause tooth loss, compared to the ideal alignment (i.e., the reference group). Mandibular segments with mild crowding had 16% greater hazard (HR = 1.16, 95% CI = 0.34-3.94) of all-cause tooth loss, compared to the reference group. Mandibular segments with moderate to severe crowding had 76% greater hazard (HR = 1.76, 95% CI = 0.55-5.66) of all-cause tooth loss, compared to the reference group. Mandibular segments with moderate irregularity had 5% greater hazard (HR = 1.05, 95%

CI = 0.62-1.80) of all-cause tooth loss, compared to no/mild irregularity (i.e., the reference group). Maxillary segments with severe irregularity had 43% greater hazard (HR = 1.43, 95% CI = 0.81-2.52) of all-cause tooth loss, compared to the reference group.

DISCUSSION

These findings showed that incisor malalignment traits in older men are associated with a greater hazard of anterior all-cause tooth loss. The exception to this statement was in the maxillary segment, for which a protective association was observed when using incisor irregularity as a predictor. This protective association principally corresponded to a higher event rate in the no/mild irregularity group because of the longer person-year follow-up time (approximately three times more), compared to any other subcategory. Thus, the findings should be interpreted with caution. The only adjusted hazard ratio with statistical significance was in the anterior maxillary segments where spacing had a 401% significantly greater hazard (HR = 5.01, 95% CI = 1.16-21.64) of all-cause tooth loss, compared to the ideal alignment. In this survival model, the adjusted 95% CI was wide. This finding indicates that the uncertainty is greater and that further information is needed to confirm such a significant prediction. This does not diminish the results, but provides evidence that the data are consistent with a wide range of values, owing to the limited number of all-cause tooth loss events (approximately 5%). Furthermore, the scientific explanation for such a significant predication could be because of the likelihood of primary or secondary occlusal trauma with flared anterior teeth for instances of spacing (Jernberg et al. 1983; Greenstein et al. 2008). Compared to any other segment in the oral cavity, the maxillary anterior teeth have large roots that may increase the destructive lateral forces on their supporting periodontal structures (Misch 2008). These explanations may intensify the effect of periodontitis, which is the leading cause for tooth extractions at the tooth level (Phipps and Stevens 1995). Our analysis was conducted at the tooth level where dental caries is not the main reason for tooth loss (Richards et al. 2005). Available data show that spacing is inversely associated with the occurrence of dental caries (John J. Warren et al. 2003). It is accordingly intuitive to generally exclude its effect in individuals with incisor spacing. We also considered that the greater hazard of all-cause tooth loss in cases of spacing and crowding in the mandibular segments or with crowding in maxillary segment is very much related to periodontal disease rather than to dental caries. This is primarily because of the much-pronounced and consistent association between malalignment and periodontal disease, compared to dental caries (Hixon et al. 1962; Roder and Arend 1971; Buckley 1972; Ainamo 1972; Silness and Roynstrand 1985; Helm and Petersen 1989b; Staufer and Landmesser 2004; Ngom et al. 2006; Buczkowska-Radlinska et al. 2012). It is important that the data were collected as an all-cause tooth loss and any statement on whether periodontal disease or dental caries is the main cause of tooth loss is an assumption from available evidence in the current literature. Other contributing factors to tooth loss are dental trauma, and tooth extractions due to patient–dentist-related decisions. These factors should not be excluded; however, their reporting or occurrences are much less, compared to the effect of periodontal disease and dental caries.

The strengths of our study include the use of a well-designed longitudinal study protocol, and a robust survival tooth level analysis with a long period of follow up. This is the first longitudinal study to report on the predictive power of malalignment traits on the rate of all-cause tooth loss. However, the study has several important limitations. The generalizability of the results is limited because it only includes Caucasian males. Because of the incomplete set of posterior teeth at baseline, only maxillary and mandibular anterior teeth were available for analysis. In both arches, the severity of malalignment traits was not great, thereby restricting our ability to observe the effect of severe malalignment on all-cause tooth loss. Our data were limited to the anterior segments where the fewest events of tooth loss are expected (Battistuzzi et al. 1987; Marcus et al. 1996). This contributed to imprecise estimates and larger variability in our statistical models.

In conclusion, certain incisor malalignment traits can be potential predictors of all-cause tooth loss. These data suggest that incisor malalignment may intensify existing poor oral health conditions that lead to tooth loss. More longitudinal studies are needed to confirm this association by using a full mouth tooth level analysis in populations with severely malaligned teeth. These results should be highly important to clinicians (e.g., periodontists and orthodontists) to motivate their patients to seek orthodontic treatment early in life to avoid the harmful sequelae of malalignment traits.

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Table 3.1. Distribution of the maxillary incisor alignment by selected characteristics of the study participants at baseline (n = 2400)

Characteristics	**Maxillary Incisor Alignment**		
	Spacing (n = 1152)	**Ideal Alignment (n = 672)**	**Crowding (n = 546)**
Age (y), mean ± SD	49.4 ± 7.6	49.4 ± 7.3	49.4 ± 7.2
Educational level (%) [b]			
High school or some college	30.7	22.2	24.2
College graduate	69.3	77.8	75.8
Smoking status (%)			
Nonsmoker	68.8	69.2	69.2
Smoker	31.2	30.8	30.8
Flossing frequency (%)			
Never	44.3	41.9	42.9
At least once per month	55.7	58.1	57.1
Brushing frequency (%) [b]			
Once a week or less	32.5	36.8	53.9
Twice a week of more	67.5	63.2	46.1

[a] Difference between the levels of alignment; $P < 0.05$, based on analysis of variance.

[b] Differences between levels of alignment; $P < 0.05$, based on the Chi-Square statistic.

SD, standard deviation.

Table 3.2. Distribution of maxillary incisor irregularity by selected characteristics of the study participants at baseline (n = 2400)

Characteristics	**Maxillary Incisor Irregularity**		
	No/Mild (n = 1632)	**Moderate (n = 486)**	**Severe (n = 282)**
Age (y), mean ± SD [a]	49.3 ± 7.8	50.3 ± 7.0	48.2 ± 8.1
Educational level (%) [b]			
High school or some college	26.1	25.9	31.9
College graduate	73.9	74.1	68.1
Smoking status (%)			
Nonsmoker	68.8	70.4	68.1
Smoker	31.3	29.4	31.9
Flossing frequency (%) [b]			
Never	43.8	38.3	48.9
At least once\month	56.2	61.7	51.1
Brushing frequency (%)			
Once a week or less	38.4	37.0	42.6
Twice a week of more	61.6	63.0	57.4

[a] Difference between the levels of irregularity; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of irregularity; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation

Table 3.3. Distribution of mandibular incisor alignment by selected characteristics of the study participants at baseline (n = 2448)

Characteristics	**Mandibular Incisor Alignment**			
	Spacing (n = 576)	**Ideal Alignment (n = 456)**	**Mild Crowding (n = 810)**	**Moderate/Severe Crowding (n = 606)**
Age (y), mean ± SD [a]	49.5 ± 7.5	47.9 ± 7.8	50.0 ± 8.0	50.0 ± 7.3
Educational level (%) [b]				
High school or some college	29.2	27.6	28.9	19.8
College graduate	70.8	72.4	71.1	80.2
Smoking status (%) [b]				
Nonsmoker	63.5	64.5	72.6	72.3
Smoker	36.5	35.5	27.4	27.7
Flossing frequency (%) [b]				
Never	51.0	39.5	45.9	36.6
At least once\month	49.0	60.5	54.1	63.4
Brushing frequency (%) [b]				
Once a week or less	37.5	38.2	35.1	41.6
Twice a week of more	62.5	61.8	64.9	58.4

[a] Difference between the levels of alignment; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of alignment; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation.

Table 3.4. Distribution of mandibular anterior irregularity by selected characteristics of the study participants at baseline (n = 2448)

Characteristics	**Mandibular incisor irregularity**		
	No/Mild (n = 1230)	**Moderate (n = 792)**	**Severe (n = 426)**
Age, mean ± SD [a]	50.7 ± 7.7	50.5 ± 7.7	50.0 ± 7.5
Educational Level (%) [b]			
High school or some college	29.8	25.0	23.5
College graduate	70.2	75.0	76.5
Smoking status (%) [b]			
Nonsmoker	65.4	70.5	73.0
Smoker	34.6	29.5	27.0
Flossing frequency (%) [b]			
Never	47.3	40.2	42.2
At least once\month	52.7	59.8	57.8
Brushing frequency (%)			
Once a week or less	36.8	39.4	38.8
Twice a week of more	63.7	60.6	61.2

[a] Difference between the levels of irregularity; $P < 0.05$, based on analysis of variance.
[b] Difference between the levels of irregularity; $P < 0.05$, based on the Chi-Square statistic.
SD, standard deviation.

Table 3.5. Survival analysis of tooth loss in the maxillary anterior segment (n = 2400)

Alignment Status	**Crude Model** [a] **Unadjusted Hazard Ratio (95% CI)**	**Crude Model** [a] ***P* Value**	**Adjusted Model** [a,b] **Adjusted Hazard Ratio (95% CI)**	**Adjusted Model** [a,b] ***P* Value**
Anterior tooth size–arch length discrepancy index				
Ideal alignment (n = 672)	Reference		Reference	
Spacing (n = 1152)	4.16 (1.22-14.17)	0.02	5.01 (1.16-21.64)	0.03
Crowding (n = 546)	2.00 (0.56-7.17)	0.23	1.95 (0.40-9.41)	0.41
Incisor Little's irregularity				
No/mild irregularity (n = 1632)	Reference		Reference	
Moderate irregularity (n = 486)	0.33 (0.08-1.36)	0.12	0.30 (0.07-1.23)	0.10
Severe irregularity (n = 282)	0.60 (0.18-1.98)	0.40	0.36 (0.09-1.36)	0.13

[a] Adjusted for lack of proportional hazards. lack of proportionality was identified in the interaction term between age and a function of survival time where the effect of age is increased somewhat by follow-up time (β = -0.01, $P = 0.02$).

[b] Values are based on cox proportional multivariate survival regression models comparing alignment status while adjusting for age in years, college education (yes/no), smoking (yes/no), flossing (never/ever), brushing (≤1 times a day/≥2 times a day), and the interaction between age and function of survival.

CI, confidence interval.

Table 3.6. Survival analysis of tooth loss in the mandibular anterior segment (n = 2448)

Alignment Status	**Crude model** **Unadjusted Hazard ratio (95% CI)**	**Crude model** ***P* Value**	**Adjusted Model [a]** **Adjusted Hazard Ratio (95% CI)**	**Adjusted Model [a]** ***P* Value**
Anterior tooth size–arch length discrepancy index				
Ideal alignment (n = 456)	Reference		Reference	
Spacing (n = 576)	1.81 (0.52-6.27)	0.35	1.60 (0.42-6.05)	0.49
Mild crowding (n = 810)	0.94 (0.26-3.34)	0.92	1.16 (0.34-3.94)	0.80
Moderate to severe crowding (n = 606)	1.84 (0.54-6.28)	0.33	1.76 (0.55-5.66)	0.34
Incisor Little's irregularity				
No/mild irregularity (n = 1230)	Reference		Reference	
Moderate irregularity (n = 792)	1.15 (0.50-2.67)	0.74	1.05 (0.62-1.80)	0.85
Severe irregularity (n = 426)	1.71 (0.71-4.10)	0.23	1.43 (0.81-2.52)	0.22

[a] The values are based on cox proportional multivariate survival regression models comparing the alignment status while adjusting for age in years, college education (yes/no), smoking (yes/no), flossing (never/ever), and brushing (≤1 times a day/≥2 times a day).

CI, confidence interval.

JOURNAL ARTICLE THREE

Incisor Malalignment and the Risk for Dental Caries

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ABSTRACT

The purpose of this repeated-measure multiple cross-sectional study was to assess the association between incisor malalignment and anterior dental caries (i.e., coronal caries, root caries) using 20 years of follow up data. In 1971–1976, plaster casts were obtained as part of the Veterans Affairs Dental Longitudinal Study (DLS) clinical examination. For a period of 9–10 years, incisor alignment was stable, as examined in a convenience sample of DLS participants. In 1984–1988, dental caries (i.e., coronal and root caries) was added to the DLS data collection procedure. We identified 211 maxillary and mandibular casts with a complete set of anterior teeth of men who completed at least one follow-up examination from the baseline dental caries record. Arch-specific incisor malalignment traits were determined using two methods: the anterior tooth size–arch length discrepancy (aTSALD) index and Little's Irregularity Index (LII). Computed arch-specific anterior coronal and root caries outcome variables included coronal decayed and filled surfaces/teeth (CDFS/T) and at least one tooth with decayed and filled root (RDFT, >0). Fixed/mixed effect models were used to compute the beta (β) estimates and 95% confidence intervals (95% CI) of the amount of change in anterior coronal caries outcomes (e.g., CDFS/T) by the level of incisor malalignment traits. Generalized estimating equations were used to compute the odds ratios (OR) and 95% CI of having anterior root caries (i.e., RDFT >0) by the level of incisor malalignment traits. Adjusted multivariate mixed/fixed effect repeated-measure analysis showed that incisor spacing in the maxillary segment, when compared to ideally aligned teeth, significantly decreased the mean maxillary anterior CDFT by 0.93 teeth (β = -0.93, 95% CI = -1.62 to - 0.24).

We observed a negative relationship between moderate and severe incisor irregularity in the anterior maxillary and mandibular segments with per arch-specific anterior CDFS, compared to no/mild irregularity; however, this finding was not statistically significant. Crowded maxillary and mandibular incisors had a higher mean CDFS, compared to the ideal alignment. There was an increased odds of anterior root caries development with malaligned arches. Certain incisor malalignment traits were linked to the anterior dental caries incidence.

Keywords: coronal caries, root caries, malalignment, irregularity, crowding, aging

INTRODUCTION

In the United States, approximately one-fourth of older adults (age, 45–64 years) have untreated dental caries (Dye et al. 2015). Effectively planning preventive strategies against the occurrence of early carious stages should be of primary concern to control such widespread disease (Hurlbutt and Young 2014). One tactic of preventing caries at the early phases of an individual's lifetime is to identify its potential causative factors. Dental malalignment is a source of food collection and plaque retention (Helm and Petersen 1989a). To that end, it seems intuitive that dental malalignment perhaps increases the occurrence of dental caries. However, there is limited evidence available regarding the effect of malalignment on the incidence of dental caries (Hafez et al.

2012). Available cross-sectional studies show conflicting results: several studies (Hixon et al. 1962; Roder and Arend 1971; Helm and Petersen 1989a; Stahl and Grabowski 2004; Buczkowska-Radlinska et al. 2012) showed a significant positive association, other studies (Hixon et al. 1962; Katz 1978; Alsoliman 2010) reported a significant negative association, and some other studies (Staufer and Landmesser 2004; Addy et al. 1988) showed no significant association between malalignment of the teeth and dental caries. A recent systematic review (Hafez et al. 2012) found that there is an increased need for longitudinal data to clarify if dental malalignment is a risk factor for dental caries development. To the best of our knowledge, the association between dental malalignment and dental caries (i.e., coronal and root caries) has not been reported in a repeated-measures cross-sectional study. Therefore, we used data from a study of aging and oral health to determine whether incisor malalignment is associated with the incidence of anterior dental caries, at both the coronal and root level.

MATERIAL AND METHODS

The participants were older men enrolled in the Dental Longitudinal Study (DLS), the oral health division of the closed-panel Veterans Affairs (VA) Normative Aging Study (NAS) in Boston, Massachusetts (Bell et al. 1966; Kapur et al. 1972). From 1969 to 2009, dental and medical examinations were collected every 2–4 years from the DLS participants in the first five recall visits (1969–1985); alginate impressions and plaster casts of the maxillary and mandibular arches were obtained. The highest number of casts with a complete set of sextants (maxillary sextants: from 6 to 11; mandibular sextants: from 22 to 27) were collected in the second recall visit (1971–1976), with a total of 476 maxillary and mandibular casts. Of these, a convenience sample of 39 participants showed that incisor alignment traits were stable over the first decade of the DLS data collection. Dental caries (i.e., coronal and root caries) was a part of the DLS dental examination beginning in 1969. However, there was no separate accountability between the incidence of coronal, and root caries until the sixth recall visit in 1984. Hence, our baseline records included participants that had measurable maxillary and mandibular casts with a complete set of sextants in the second recall examination (1971–1976), paired with a complete dental examination with no reported tooth loss in the anterior area at the sixth recall examination (1984–1988). Participants had at least one follow-up examination from our baseline dental examination record (1984–1988). We thus identified 211 participants with measurable maxillary and mandibular plaster casts. All participants signed a written informed consent form before each examination. The study was approved by the institutional review boards of Boston University Medical Center (Boston, MA) and the VA Boston Healthcare System. This report complies with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies.

Dental Caries

From 1984 to 2009 (i.e., sixth DLS recall visit), every 2 to 4 years, a calibrated periodontist (Raul Garcia) used universally accepted standardized measurement methods to perform a comprehensive clinical and radiographic dental examination that involved recording dental caries (i.e., coronal and root caries). By using an explorer on four surfaces per anterior tooth in each arch segment (i.e., from canine to canine), separate counts were made between coronal and root caries lesions or restorations. Sound coronal or root surfaces were free of clinical and radiographic signs of caries or restorations. A restored coronal or root surface was carious if it had any clinical or radiographic signs of caries recurrence. For cases of carious lesions concurrently occurring on the same coronal and root surface, the recorded lesion was considered a root caries if one of the following conditions was present: (1) even distribution of the carious lesion on the coronal and root surface, (2) a carious lesion extending more than 2 mm into the root surface, and (3) most of the carious lesion was apical to the cement-enamel junction. In the coronal and root portions, the per arch anterior sum (i.e., canine to canine) of decayed surfaces (coronal [CDS], root [RDS]) and decayed teeth (coronal [CDT], root [RDT]), and per arch sum of filled surfaces (coronal [CFS], root [RFS]) and filled teeth (coronal [CFT], root [RDT]) were computed. Further computation in the coronal and root portions included the per arch anterior sum of decayed and filled surfaces (coronal [CDFS], root [RDFS]) and decayed and filled teeth (coronal [CDFT], root [RDFT]). Because of the low incidence of root caries in our sample, a further definition of at least one root decayed and filled tooth (RDFT ≥0) was computed for each anterior arch.

Incisor Malalignment and Irregularity

From the alginate impressions obtained by a calibrated periodontist in the second recall visit (Edward Loftus; 1971–1976), plaster dental casts were used to measure the per arch incisor malalignment traits (maxillary incisors: from 6 to 11; mandible incisors: from 22 to 27). Per arch malalignment traits in the anterior segments were quantified using two methods of measurement (Little 1975; Harris et al. 1987). First, to account for the inadequate arch space in relation to tooth size, the anterior tooth size–arch length discrepancy index (aTSALD) was used through computing the difference between the space available and the space required, with negative values indicating crowding (Harris et al. 1987). The sum of the maximum mesiodistal widths of the anterior teeth (i.e., canine to canine) provided the amount of space required. From the maximum point of canines distally, the available space was determined through the arch best fit by using a flexible ruler placed on the incisor surfaces. The arch best fit was identified as the even curve accommodating the most teeth. In accordance with the Index of Orthodontic Treatment Needs, incisor malalignment was grouped by spacing (>0 mm); ideal alignment (0 mm); mild crowding (<0 mm and ≥-2 mm); and moderate to severe crowding (<-2 mm) (Brook and Shaw 1989). In the maxillary arch, because of having few cases of moderate to severe crowding, only one subcategory of crowding (<0 mm) was used. To account for the labiolingual incisor displacement, Little's Irregularity Index (LII) method) (Little 1975) was adopted by using a digital caliper placed parallel to the occlusal plane to measure the sum of labiolingual linear displacement of anatomical contact points in the anterior sextants (maxillary incisors: from 6 to 11; mandible incisors: from 22 to 27). The severity of incisor irregularity was categorized as no/mild irregularity (≥0 mm and <4 mm), moderate irregularity (≥4 mm and ≤6 mm), or severe irregularity (>6 mm) (Little 1975). Using 50 randomly selected casts, excellent interclass correlation of >0.98 was noted across all malalignment traits (i.e., upper incisor alignment, lower incisor alignment, upper incisor irregularity, and lower incisor irregularity).

Other information

After rinsing with a disclosing agent, an ordinal scale was used to record plaque (score 0, none; score 1, interproximal surfaces only; score 2, interproximal surfaces continuing onto labial or lingual sites; and score 3, all surfaces covering more than two-thirds of the tooth). Supragingival calculus was similarly measured by an ordinal scale (score 0, none; score 1, discontinuous flecks; score 2, non-continuous band on the tooth surfaces; and score 3, continuous band on the tooth surfaces). For each anterior arch, we calculated the mean plaque, and calculus scores. Other covariates in our data included age in years; income (low, <\$20,000; middle, ≥\$20,000 and <\$30,000; high, ≥\$30,000); educational level (high school or some college, college graduate); current smoking status (yes/no); number of medications; flossing (never, and at least one a month); brushing (once a week or less, twice a week or more); use of fluoride tooth paste (yes/no); use of fluoride mouth wash (yes/no), quality and quantity of saliva (limited/copious), any dental treatment in the past year, any gum treatment in the past year (yes/no), any prophylaxis cleanings in the past year (yes/no), ever lived in an area with community water fluoridation (yes/no), number of teeth remaining in each anterior arch, and number of teeth remaining in the whole mouth.

Statistical methods

Analysis of variance (ANOVA) and the chi-square test were used to identify any statistical association between malalignment traits (i.e., upper incisor alignment, lower incisor alignment, upper incisor irregularity, and lower incisor irregularity) and dental caries (i.e., coronal caries outcome variables [CDS, CFS, CDFS, CDT, CFT, CDFT] and root caries outcome variables [RDS, RFS, RDFS, RDT, RFT, RDFT, and RDFT ≥ 0]). In each specific arch, multivariate linear mixed/fixed effect models were used to estimate the effect of malalignment traits on the incidence of coronal caries at the surface and tooth levels (i.e., CDFS, CDFT). Multivariate generalized estimating equations (GEE) regression analyses were used to estimate the per arch odds of having at least one decayed and filled tooth (RDFT >0) by malalignment traits strata. These repeated-measure models had an autoregressive within-subject correlation matrix with a time factor (i.e., time) to cluster the observations and to control for correlation in the outcome data. Confounders were defined as covariates that showed a significant association with the outcome variable or changed the coefficient of the main predictor by $>10\%$. Statistical significance was evaluated at the 0.05 levels. All statistical analyses were conducted using SAS software, version 9.4.

RESULTS

Arch-specific baseline characteristics by malalignment traits are shown in Tables 4.1–4.8. Overall, this subset of the DLS data were limited to self-motivated and healthier enrollees since they had been participating in data collection since 1969 and had completed one recall visit after our baseline record (i.e., 1984–1988), which resulted in at least 20 years of voluntary involvement. Participants were in their early seventh decade and mostly college educated, none were smokers, had copious amount of saliva, had acceptable access to dental treatment, decent flossing practice, and lived in an area with community water fluoridation. The anterior mandibular plaque and calculus mean scores (4.2 ± 3.2 and 5.8 ± 3.7, respectively) were higher than the opposing anterior maxillary plaque and calculus scores (2.3 ± 2.6 and 0.4 ± 1.4, respectively). The maxillary and mandibular anterior segments had higher filled surfaces (7.8 ± 6.6 and 1.1 ± 2.7, respectively) than decayed surfaces (0.6 ± 1.0 and 0.2 ± 0.5, respectively). The maxillary anterior coronal decayed and filled surfaces (i.e., CDFS) ranged from 0 to 24 (8.5 ± 6.7), whereas the mandibular anterior coronal decayed and filled surfaces (i.e., CDFS) ranged 0–20 (1.3 ± 2.9). The proportion of at least one root decayed and filled teeth (i.e., RDFT >0) in the maxillary anterior arch (22.3%) was similarly higher than the proportion of at least one root decayed and filled teeth (i.e., RDFT >0) in the mandibular anterior arch (12.3%). Repeated-measure models were only adjusted for possible confounders when the crude estimates showed a statistical significance. Table 4.9 shows the beta (β) estimates from the crude and adjusted repeated-measure mixed/fixed effect model for incidence of anterior coronal caries by maxillary incisor alignment status. The β estimates were adjusted for age, anterior maxillary mean plaque score, anterior maxillary mean calculus score, college education (yes/no), flossing (never, ever), brushing (≤1 times a day, ≥2 times a day), salivary flow (limited, copious), income (low, ≤$14,999; middle, $$15,000–$24,999; high, ≥$25,000), and number of remaining teeth in the anterior maxillary arch. Table 4.10 shows the β estimates from the crude repeated-measure mixed/fixed effect model for the incidence of anterior coronal caries by maxillary incisor irregularity status. Tables 4.11 and 4.12 show the β estimates from crude repeated-measure mixed/fixed effect model for the incidence of anterior coronal caries by mandibular incisor alignment and irregularity status, respectively. Tables 4.13 and 4.14 show the odds ratio (OR) from crude repeated-measure generalized estimating equations (GEE) models for the incidence of at least one tooth with root caries (i.e., RDFT >0) in the anterior maxillary segment by maxillary incisor alignment traits. Tables 4.15 and 4.16 show the OR from crude repeated-measure generalized estimating equations (GEE) models for the incidence of at least one tooth with root caries (i.e., RDFT >0) in the anterior mandibular segment by mandibular incisor alignment traits.

The Association Between Maxillary Alignment Traits and Coronal Caries Outcomes

After controlling for related covariates, the multivariate mixed/fixed effect repeated-measure analysis showed that maxillary anterior arches with incisor spacing had a lower mean maxillary anterior CDFS score (β = -1.95, 95% CI = -4.15 to 0.26), compared to the ideal alignment (i.e., the reference group). In the same model, crowding had a 0.61 higher mean maxillary anterior CDFS score (β = -0.61, 95% CI = -1.90 to 3.13), compared to the reference group. These results were not statistically significant; however, when using the alignment status as a continuous predictor rather than as a categorical predictor, the adjusted multivariate analysis showed that a 1-mm increase (i.e., towards more spacing) in the maxillary incisor alignment status significantly decreased the predicted value of maxillary anterior CDFS by 0.72 surfaces (β = -0.72, 95% CI = -1.14 to - 0.30). This finding is primarily because of increased statistical variability in the continuous predictor. Furthermore, after controlling for related covariates, the multivariate mixed/fixed effect repeated-measure analysis showed that incisor spacing in the maxillary segment significantly decreased the mean maxillary anterior CDFT by 0.93 teeth (β = -0.93, 95% CI = -1.62 to - 0.24). Using the continuous variable of maxillary incisor alignment status in the multivariate model similarly showed that a 1-mm increase (i.e., towards more spacing) in the alignment status significantly decreased the mean maxillary anterior CDFT by 0.30 teeth (β = -0.30, 95% CI = -0.43 to - 0.17). Furthermore, multivariate analyses showed that incisor crowding in the maxillary segment increased the mean the mean maxillary anterior CDFT by 0.24 (β = 0.24, 95% CI = -0.54 to 1.02). When using maxillary incisor irregularity as a predicator for maxillary anterior CDFS, none of the multivariate results were statistically significant. A similar phenomenon occurred when using maxillary incisor irregularity as a predictor for maxillary anterior CDFT. Crude analysis from the mixed/fixed effect repeated-measure analysis showed that moderate maxillary incisor irregularity had 1.03 less mean maxillary anterior CDFS (β = -1.03, 95% CI = -1.24 – 3.31), compared to no/mild maxillary incisor irregularity (i.e., the reference group). In the same crude model, severe maxillary incisor irregularity had 1.07 less mean maxillary anterior CDFS (β = -1.07, 95% CI = -4.07 to 1.94), compared to the reference group. When using maxillary incisor irregularity to predict the value of the mean maxillary anterior CDFS, the crude mixed/fixed effect model showed that a 1-mm increase in maxillary incisor irregularity decreases the mean maxillary anterior CDFS by 0.15 (β = -0.15, 95% CI = -0.57 to 0.27). Crude analysis from the mixed/fixed effect repeated-measure analysis showed that moderate maxillary incisor irregularity had 0.41 more mean maxillary anterior CDFT (β = 0.41, 95% CI = -0.33 to 1.16), compared to no/mild maxillary incisor irregularity (i.e., the reference group). In the same crude model, severe maxillary incisor irregularity had 0.27 more mean maxillary anterior CDFT (β = 0.27, 95% CI = -0.71 to 1.26), compared to the reference group. When using maxillary incisor irregularity to predict the value of mean maxillary anterior CDFT, the crude mixed/fixed effect model showed that a 1-mm increase in maxillary incisor irregularity increased the mean maxillary anterior CDFS by 0.01 (β = 0.01, 95% CI = -0.13 to 0.15). The differences observed when using maxillary incisor irregularity to predict the mean maxillary anterior CDFS and CDFT were primarily due to the differences in statistical variability in these outcome measures. To that end, interpretations should be performed with caution, because none of the observed results is statistically significant.

The Association Between Mandibular Alignment Traits and Coronal Caries Outcomes

The results of the crude mixed/fixed effect repeated-measure analysis to test the association between mandibular alignment traits (i.e., mandibular incisor alignment, and mandibular incisor irregularity) and mandibular coronal caries outcomes (i.e., CDFS, CDFT) did not show any statistical significance. Crude analysis from the mixed/fixed effect repeated-measure analysis showed that spacing in the mandibular segment had 0.19 more mean mandibular anterior CDFS (β = 0.19, 95% CI = -1.15 to 1.52), compared to the ideal alignment (i.e., the reference group). In the same model, crude analysis of the mixed/fixed effect repeated-measure analysis showed that mild crowding in the mandibular segment had 0.23 more mean mandibular anterior CDFS (β = 0.23, 95% CI = -0.94 to 1.40), compared to the reference group. In the same model, the crude analysis from the mixed/fixed effect repeated-measure analysis also showed that moderate to severe crowding in the mandibular segment had 0.05 less mean mandibular anterior CDFS (β = -0.05, 95% CI = -1.31 to 1.21), compared to the reference group. Using the continuous variable of the mandibular incisor alignment status in the crude model showed that a 1-mm increase (i.e., towards more spacing) in the alignment status increased the mean mandibular anterior CDFS by 0.07 surfaces (β = 0.07, 95% CI = -0.10 to - 0.24). Furthermore, crude analysis from the mixed/fixed effect repeated-measure analysis showed that spacing in the mandibular segment had 0.20 more mean mandibular anterior CDFT (β= 0.20, 95% CI = -0.44 – 0.83), compared to the ideal alignment (i.e., the reference group). In the same model, crude analysis from the mixed/fixed effect repeated-measure analysis showed that mild crowding in the mandibular segment had 0.23 more mean mandibular anterior CDFT (β = 0.23, 95% CI = -0.33 to 0.78), compared to the reference group. In the same model, crude analysis from the mixed/fixed effect repeated-measure analysis also showed that moderate to severe crowding in the mandibular segment had 0.23 higher mean mandibular anterior CDFT (β = 0.23, 95% CI = -0.37 to 0.83), compared to the reference group. Using the continuous variable of mandibular incisor alignment status in the crude model showed that a 1-mm increase (i.e., towards more spacing) in the alignment status increased the mean mandibular anterior CDFT by 0.02 surfaces (β = 0.02, 95% CI = -0.06 to - 0.10). Furthermore, crude mixed/fixed effect repeated-measure analysis showed that moderate irregularity in the mandibular segment had 0.12 less mean mandibular anterior CDFS (β = -0.12, 95% CI = -1.05 to 0.80), compared to no/mild irregularity (i.e., the reference group). In the same model, crude analysis showed that severe irregularity in the mandibular segment had 0.12 less mean mandibular anterior CDFS (β = - 0.12, 95% CI = -1.29 to 1.05), compared to the reference group. Using the continuous variable of the mandibular incisor irregularity status in the crude model showed that a 1-mm increase (i.e., towards more spacing) in the alignment status decreased the mean mandibular anterior CDFS by 0.01 surfaces (β = - 0.01, 95% CI = -0.20 to 1.18). Crude mixed/fixed effect repeated-measure analysis showed that moderate irregularity in the mandibular segment had 0.01 more mean mandibular anterior CDFT (β = 0.01, 95% CI = -0.43 to 0.45), compared to no to mild irregularity (i.e., the reference group). In the same model, crude analysis showed that severe irregularity in the mandibular segment had 0.05 less mean mandibular anterior CDFT (β = -0.05, 95% CI = -0.61 to 0.51), compared to the reference group. Using the continuous variable of mandibular incisor irregularity status in the crude model showed that a 1-mm (i.e., towards more spacing) increase in the alignment status increased the mean mandibular anterior CDFT by 0.05 surfaces (β = 0.05, 95% CI = -0.09 to 0.10).

The Association Between Maxillary Alignment Traits and Root Caries Outcomes

Crude GEE models indicated that maxillary incisor spacing had 0.82 odds (OR = 0.82, 95% CI, 0.46 - 1.44) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior maxillary arch relative to maxillary incisor ideal alignment (i.e., the reference group). Using the same model, maxillary incisor crowding had 1.32 odds (OR = 1.32, 95% CI, 0.72 - 1.32) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior maxillary arch relative to the reference group. Using the continuous variable of maxillary incisor alignment status in a GEE crude model showed that a 1-mm increase (i.e., towards more spacing) in the alignment status had 0.94 odds (OR= 0.94, 95% CI, 0.83-1.05) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior maxillary arch. Crude GEE models indicated that moderate maxillary incisor irregularity had 1.09 odds (OR = 1.09, 95% CI, 0.61-1.94) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior maxillary arch relative to no to mild irregularity in the anterior maxillary segment (i.e., the reference group). Using the same model, severe maxillary incisor irregularity had 1.88 odds (OR = 1.88, 95% CI, 0.81 - 4.37) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior maxillary arch relative to the reference group. Using the continuous variable of maxillary incisor irregularity status in a GEE crude model showed that a 1-mm increase in the alignment status had 1.03 odds (OR = 1.03, 95% CI, 0.92-1.16) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior maxillary arch.

The Association Between Mandibular Alignment Traits and Root Caries Outcomes

Crude GEE models indicated that mandibular incisor spacing had 2.81 odds (OR = 2.81, 95% CI, 0.92-8.70) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior mandibular arch relative to mandibular incisor ideal alignment (i.e., the reference group). Using the same model, mandibular incisor mild crowding had 2.38 odds (OR = 2.38, 95% CI, 0.83-6.78) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior mandibular arch relative to the reference group. Using the same model, mandibular incisor moderate to severe crowding had 2.04 odds (OR = 2.04, 95% CI, 0.67 to 6.19) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior mandibular arch relative to the reference group. Using the continuous variable of mandibular incisor alignment status in a GEE crude model showed that a 1-mm increase (i.e., towards more spacing) in the alignment status had 1.02 odds (OR = 1.02, 95% CI, 0.90 - 1.16) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior mandibular arch. Crude GEE models indicated that moderate mandibular incisor irregularity had 1.35 odds (OR = 1.35, 95% CI, 0.68-2.67) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior mandibular arch relative to no to mild irregularity in the anterior maxillary segment (i.e., the reference group). Using the same model, severe maxillary incisor irregularity had 1.17 odds (OR = 1.17, 95% CI, 0.46-3.02) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior mandibular arch relative to the reference group. Using the continuous variable of mandibular incisor irregularity status in the GEE crude model showed that a 1-mm increase in the alignment status had 1.06 odds (OR = 1.06, 95% CI, 0.91 - 1.23) of having at least one decayed and filled tooth (i.e., RDFT >0) in the anterior mandibular arch.

DISCUSSION

Using an arch-specific repeated-measure analysis, we examined the associations of incisor malalignment traits by using two validated and reliable methods (i.e., aTSALD and LII) with anterior coronal caries (CDFS and CDFT) and root caries (RDFT >0) outcomes. Dental caries (i.e., coronal and root caries) status was evaluated one decade after the information about incisor alignment was collected; therefore, this study should not be considered as longitudinal in design but as a multiple cross-sectional type of design. The design of this multiple cross-sectional study provided an exceptional opportunity to test our hypothesis using a robust repeated-measure analysis with a long follow-up time. This subset of the DLS data included unique participants because they were self-motivated and healthier enrollees, compared to their peers. The participation was voluntary, despite the older age (i.e., seventh decade) of our participants. In addition, of all other DLS enrollees, our participants had a complete set of anterior teeth, indicating their oral health compliance and self-oral care. This was further proven as they were mostly college educated, had no smoking habits, had copious amount of saliva, had acceptable access to dental treatment, decent flossing practice, and lived in an area with community water fluoridation.

Because malalignment is highest in the incisor area (Staufer and Landmesser 2004), analyses were confined to the anterior segments. Furthermore, we used an arch-specific analyses to allow a comparison between arches and to account for the difference in the anatomical and morphological features between maxillary and mandibular anterior sextants ("Wheeler's Dental Anatomy, Physiology and Occlusion - Stanley J. Nelson" 2016). To the best of our knowledge, this study is the first to rigorously test the association between incisor malalignment and irregularity with per arch anterior-specific dental caries outcomes at the coronal and root levels. In fact, the association between incisor malalignment traits and anterior root caries was never reported previously. Furthermore, no study has looked at the effect of crowding alone on the development of coronal caries. When using incisor irregularity as a predictor for anterior coronal caries, the reported studies used invalid and unreliable incisor irregularity indices (Hixon et al. 1962; S. Helm and Petersen 1989a; Buczkowska-Radlinska et al, 2012). Furthermore, one study (Buczkowska-Radlinska et al. 2012) attempted to examine the relationship between incisor irregularity and complete mouth caries experience. This action introduces a methodological error because the effect of incisor irregularity is considered site-specific to the occurrence of coronal or root caries, and this may overestimate their reported results. Other studies (Roder and Arend 1971; Katz 1978; Staufer and Landmesser 2004) in the literature used invalid and unreliable composite indices (e.g., combining irregularity and crowding in one index), which can introduce a misclassification bias in their results. Furthermore, the definition of coronal caries was heterogeneous across most of the available studies (Hixon et al. 1962; Roder and Arend

1971; Katz 1978; S. Helm and Petersen 1989a; Staufer and Landmesser 2004; Buczkowska-Radlinska et al. 2012).

In light of all of these factors, our results were unique owing to the robust methodological process of measuring incisor malalignment traits and the availability of a long follow-up data on dental caries incidence at the coronal and root levels. However, this factor limited our ability to compare our results with previously reported studies. The main finding in our study was that, after controlling for related covariates, the results of the multivariate mixed/fixed effect repeated-measure analysis showed that incisor spacing in the maxillary segment, when compared to ideally aligned teeth, significantly decreased the mean maxillary anterior CDFT by 0.93 teeth (β = -0.93, 95% CI = -1.62 to -0.24). This finding is in agreement with that of Helm and Peterson (Helm and Petersen 1989a) who, by using multiple regression analysis controlling for sex in a small sample of individuals (n = 16), found that maxillary incisor spacing showed 1.64 less mean decayed and filled surfaces, compared to the controls (n = 27) with ideal alignment. An explanation of these results is that closed contact points are needed to initiate proximal lesions as dental plaque develops and accumulates around them (Berman and Slack 1973; Iiellgrcn 1956). Greater food impaction is expected in spaced arches, although open contact points offer an easily accessible proximal surface for cleaning (Jernberg et al. 1983). To that end, it is logical to expect that spacing would be inversely associated with coronal caries. In our analysis, none of the other malalignment traits showed significant associations with coronal caries outcomes. We observed an inverse relationship between moderate and severe incisor irregularity in the anterior maxillary and mandibular segments with per arch-specific anterior CDFS, compared to no to mild irregularity; however, this finding was not statistically significant. These results are in agreement with one study (Katz 1978) that used a composite index to account for malalignment. Because irregular teeth tend to have deviated and separated contact points, these results were not surprising since approximating contact points are needed for caries initiation and progression (Berman and Slack 1973). On the contrary, our analysis showed that crowded maxillary and mandibular incisors had higher mean CDFS, compared to ideal alignment. This is not surprising because crowded teeth are distinct from irregular teeth in that they disrupt the normal proximal contacts in a mesiodistal rather than a labiolingual occlusal plan, which allows for less spaced and closer proximal contact points, thereby causing more plaque accumulation. To our knowledge, these results are the first to be reported in the current literature and no study has attempted to test the association between incisor crowding and anterior coronal caries. The association between incisor malalignment traits and anterior root caries has not been reported previously. Our findings were not statistically significant; however, our findings indicated an increased odds of anterior root caries development with malaligned arches. In our sample of men with malaligned arches, the presence of higher plaque scores; the high incidence of coronal caries; and the age of our participants, which exposes them to a greater risk for periodontal disease, may all contribute towards these observed associations with anterior root caries incidence (Youngs 1994). This study validates that the effect of incisor malalignment traits on dental caries is complex and dynamic (Hafez et al. 2012). As different incisor malalignment traits (i.e., incisor spacing, crowding, irregularity) coexist, it is difficult to observe or directly link its association with dental caries at the coronal and root levels. Proximal caries is a site-specific disease that is initiated by plaque accumulation with bacterial acid production (Selwitz et al. 2007). In order for this mechanism to occur, a normally or ideally aligned arch is needed (Jernberg et al. 1983). Furthermore, plaque accumulation and thus accelerated dental caries progression can be observed by certain traits of incisor malalignment in which the mesiodistal incisor planes are disrupted (i.e., crowding). However, spaced arches have a lower possibility of plaque accumulation, which led to our findings of an inverse relationship with coronal caries. It is altogether plausible to observe that the relationship of incisor malalignment is primarily related to plaque accumulation and individual-related oral practice. In general, regimens to prevent smooth surface caries lesions include the use of fluoride varnish, and robust oral health practice should be highly promoted and encouraged in populations with incisor malalignment as they encounter a disruption of the normal cleansing process between proximal contact points.

The strengths of our study include the use of a multiple cross-sectional study design with extended follow-up period, and robust statistical testing (e.g., mixed/fixed effects model and GEE model) controlling for several confounders. We also used two validated and reliable methods to account for incisor malalignment traits. In addition, one calibrated periodontist performed the dental caries clinical examination across all recall visits.

Numerous limitations exist in this study. Our data used previously recorded malalignment traits and paired them with dental examinations recorded one decade later, thereby limiting the amount of observed change in dental caries outcomes. Furthermore, because coronal caries progression is slowest in adults (Pitts 1983; Lawrence et al. 1997) and because of the few numbers of severe malalignment traits, no marked changes occurred with dental caries incidence outcomes. Underestimation is predicted in the root caries examination because subgingival calculus was not removed before the clinical examination. Participants were self-motivated and healthy Caucasian men in their seventh decade, mostly college educated, with no smoking habit, had copious amount of saliva, with acceptable access to dental treatment, decent flossing practice, and lived in an area with community water fluoridation. Only maxillary and mandibular anterior teeth were available in our analysis. This was because of the incomplete set of posterior teeth at baseline. These factors taken together may limit the generalizability of the results.

In conclusion, certain incisor malalignment traits are linked to the anterior dental caries incidence. Based on of the limitations of this study, well-designed prospective longitudinal studies with diverse populations are needed to further determine the association between incisor malalignment and dental caries. These future cohort studies should test and identify possible pathways that mediate such an association.

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Table 4.1. Distribution of the maxillary incisor alignment by selected characteristics of the study participants at baseline (n = 211)

Characteristics	**Maxillary Incisor Alignment**		
	Spacing (n = 97)	**Ideal Alignment (n = 60)**	**Crowding (n = 54)**
Age (y), mean ± SD [a]	59.9 ± 6.6	60.9 ± 7.5	60.3 ± 5.8
Number of teeth remaining, mean ± SD [a]	23.3 ± 3.4	24.5 ± 3.0	24.4 ± 2.7
Number of Medications used, mean ± SD [a]	2.1 ±1.7	2.3 ± 1.8	2.1 ± 1.7
Income [b]			
≤$14,999	36.6	30.2	32.1
$15,000–$24,999	45.1	39.0	58.5
≥$25,000	18.3	28.2	9.4
Educational Level (%) [b]			
High school or some college	26.8	18.3	25.9
College graduate	73.2	81.7	74.1
Smoking status (%)			
Nonsmoker	90.7	90.0	90.7
Smoker	9.3	10.0	9.3
Flossing frequency (%) [b]			
Never	40.2	35.0	33.3
At least once\month	59.8	65.0	66.7
Brushing frequency (%) [b]			
Once a week or less	63.9	63.3	75.9
Twice a week of more	36.1	36.7	24.1
Saliva (%) [b]			
Limited	7.2	3.3	7.6
Copious	92.8	96.7	92.5
Prophylaxis in past year (%) [b]	77.3	88.3	81.5
Dental treatment in the past year (%) [b]	65.0	53.3	72.2
Use of fluoride toothpaste (%) [b]	96.9	94.8	94.4
Use of fluoride mouthwash (%) [b]	7.2	11.7	11.1
Lived in area with community water fluoridation (%)	90.5	92.5	90.5

[a] Difference between the levels of crowding; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of crowding; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation.

Table 4.2. Distribution of maxillary incisor alignment by dental caries status of the study participants at baseline (n = 211)

Characteristics	**Maxillary Incisor Alignment**		
	Spacing (n = 97)	**Ideal Alignment (n = 60)**	**Crowding (n = 54)**
Coronal Caries			
Maxillary anterior plaque index, mean ± SD [a]	2.0 ± 2.4	2.2 ± 2.6	3.2 ± 2.7
Maxillary anterior Calculus Index, mean ± SD	0.5 ± 1.6	0.4 ± 1.3	0.5 ± 1.2
Maxillary anterior Coronal decayed surfaces, mean ± SD [a]	0.5 ± 0.8	0.9 ± 1.2	0.6 ± 1.0
Maxillary anterior Coronal filled surfaces, mean ± SD [a]	6.5 ± 6.1	8.6 ± 6.8	9.4 ± 6.7
Maxillary anterior Coronal decayed and filled surfaces, mean ± SD [a]	6.9 ± 6.3	9.5 ± 6.6	10.0 ± 6.7
Maxillary anterior Coronal decayed teeth, mean ± SD [a]	0.4 ± 0.8	0.8 ± 1.0	0.6 ± 0.9
Maxillary anterior Coronal filled teeth, mean ± SD [a]	3.0 ± 2.2	3.9 ± 1.9	4.2 ± 1.7
Maxillary anterior Coronal decayed and filled teeth, mean ± SD [a]	3.5 ± 2.5	4.6 ± 2.1	4.8 ± 2.0
Root Caries			
Maxillary anterior Root decayed surfaces, mean ± SD	0.1 ± 0.7	0.1 ± 0.5	0.1 ± 0.3
Maxillary anterior Root filled surfaces, mean ± SD [a]	0.2 ± 0.7	0.2 ± 0.5	0.3 ± 0.7
Maxillary anterior Root decayed and filled surfaces, mean ± SD	0.3 ± 0.8	0.3 ± 0.8	0.4 ± 0.8
Maxillary anterior Root decayed teeth, mean ± SD	0.1 ± 0.3	0.1 ± 0.3	0.1 ± 0.3
Maxillary anterior Root filled teeth, mean ± SD [a]	0.2 ± 0.7	0.2 ± 0.4	0.3 ± 0.7
Maxillary anterior Root decayed and filled teeth, mean ± SD [a]	0.3 ± 0.7	0.3 ± 0.6	0.4 ± 0.8
At Least one root decayed and filled tooth in the maxillary anterior arch (%) [b]	19.6	21.7	27.8

[a] Difference between the levels of crowding; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of crowding; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation.

Table 4.3. Distribution of maxillary incisor irregularity by selected characteristics of the study participants at baseline (n = 211)

Characteristics	**Maxillary Incisor Irregularity**		
	No/Mild (n = 146)	**Moderate (n = 43)**	**Severe (n = 22)**
Age (y), mean ± SD [a]	60.2 ± 7.0	61.2 ± 5.7	59.3 ± 6.2
Number of teeth remaining, mean ± SD [a]	23.9 ± 3.2	24.2 ± 2.7	23.2 ± 3.7
Number of Medications used, mean ± SD	2.2 ± 1.8	2.2 ± 1.7	2.1 ± 1.2
Income [b]			
≤$14,999	37.3	28.6	23.8
$15,000–$24,999	43.0	59.5	47.6
≥$25,000	19.7	11.9	28.6
Educational Level (%) [b]			
High school or some college	22.6	25.6	31.8
College graduate	77.4	74.4	68.2
Smoking status (%) [b]			
Nonsmoker	89.0	95.4	90.9
Smoker	11.0	4.6	9.1
Flossing frequency (%) [b]			
Never	37.0	32.6	45.5
At least once\month	63.0	67.4	54.5
Brushing frequency (%) [b]			
Once a week or less	67.8	60.5	72.7
Twice a week of more	32.2	39.5	27.3
Saliva (%) [b]			
Limited	4.8	7.0	13.6
Copious	95.2	93.0	86.4
Prophylaxis in past year (%) [b]	84.3	79.1	68.2
Dental treatment in the past year (%) [b]	62.3	62.8	72.7
Use of fluoride toothpaste (%) [b]	96.5	90.7	100
Use of fluoride mouthwash (%) [b]	8.9	9.3	13.6
Lived in area with community water fluoridation (%) [b]	89.8	92.9	94.7

[a] Difference between the levels of crowding; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of crowding; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation.

Table 4.4. Distribution of maxillary incisor irregularity by the dental caries status of the study participants at baseline (n = 211)

Characteristics	**Maxillary Incisor Irregularity**		
	No/Mild (n = 146)	**Moderate (n = 43)**	**Severe (n = 22)**
Coronal Caries			
Maxillary anterior plaque index, mean ± SD [a]	2.2 ± 2.6	2.2 ± 2.3	3.3 ± 2.4
Maxillary anterior calculus Index, mean ± SD [a]	0.4 ± 1.5	0.7 ± 1.4	0.2 ± 0.7
Maxillary anterior coronal decayed surfaces, mean ± SD	0.6 ± 1.0	0.6 ± 0.9	0.8 ± 1.1
Maxillary anterior coronal filled surfaces, mean ± SD [a]	7.8 ± 6.8	8.6 ± 6.3	6.3 ± 5.0
Maxillary anterior coronal decayed and filled surfaces, mean ± SD [a]	8.4 ± 6.9	9.2 ± 6.5	7.0 ± 5.1
Maxillary anterior coronal decayed teeth, mean ± SD	0.6 ± 0.9	0.6 ± 0.8	0.7 ± 0.9
Maxillary anterior coronal filled teeth, mean ± SD [a]	3.5 ± 2.1	3.9 ± 2.0	3.5 ± 1.6
Maxillary anterior coronal decayed and filled teeth, mean ± SD [a]	4.1 ± 2.4	4.5 ± 2.3	4.2 ± 2.0
Root Caries			
Maxillary anterior root decayed surfaces, mean ± SD [a]	0.1 ± 0.5	0.05 ± 0.2	0.5 ± 0.2
Maxillary anterior root filled surfaces, mean ± SD [a]	0.2 ± 0.6	0.2 ± 0.5	0.6 ± 0.9
Maxillary anterior root decayed and filled surfaces, mean ± SD [a]	0.3 ± 0.8	0.3 ± 0.5	0.6 ± 1.0
Maxillary anterior root decayed teeth, mean ± SD [a]	0.08 ± 0.3	0.05 ± 0.2	0.05 ± 0.6
Maxillary anterior root filled teeth, mean ± SD [a]	0.2 ± 0.6	0.2 ± 0.4	0.6 ± 0.9
Maxillary anterior root decayed and filled teeth, mean ± SD [a]	0.3 ± 0.7	0.2 ± 0.5	0.6 ± 1.0
At least one root decayed and filled tooth in the maxillary anterior arch (%) [b]	19.9	20.9	40.9

[a] Difference between the levels of crowding; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of crowding; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation.

Table 4.5. Distribution of the <u>mandibular incisor alignment</u> by selected characteristics of the study participants at baseline (n = 211)

Characteristics	**Mandibular Incisor Alignment**			
	Spacing (n = 43)	**Ideal Alignment (n = 41)**	**Mild Crowding (n = 83)**	**Moderate/Severe Crowding (n = 57)**
Age (y), mean ± SD [a]	60.4 ± 5.9	58.6 ± 7.2	60.9 ± 6.2	60.6 ± 7.3
Number of teeth remaining, mean ± SD [a]	23.4 ± 3.2	24.4 ± 4.0	23.8 ± 2.8	24.1 ± 2.8
Number of medications used, mean ± SD [a]	2.3 ± 1.7	2.7 ± 2.3	1.8 ± 1.5	2.1 ± 1.4
Income [b]				
≤$14,999	31.6	33.3	41.5	25.5
$15,000–$24,999	52.6	43.6	42.9	51.0
≤25,000	15.8	23.1	15.6	23.5
Educational level (%) [b]				
High school or some college	29.3	17.5	26.0	22.6
College graduate	70.7	82.5	74.0	77.4
Smoking status (%) [b]				
Nonsmoker	85.4	90.0	89.6	96.2
Smoker	14.6	10.0	10.4	3.8
Flossing frequency (%) [b]				
Never	53.7	42.5	33.8	24.5
At least once per month	46.3	57.5	66.2	75.5
Brushing frequency (%)				
Once a week or less	65.9	70.0	64.9	67.9
Twice a week of more	34.2	30.0	35.1	32.1
Saliva (%) [b]				
Limited	9.8	7.5	5.3	3.8
Copious	90.2	92.5	94.7	96.2
Prophylaxis in past year (%) [b]	70.7	80.0	83.1	88.7
Dental treatment in the past year (%) [b]	58.5	55.0	70.1	64.2
Use of fluoride toothpaste (%)	97.6	94.7	94.8	96.2
Use of fluoride mouthwash (%) [b]	12.2	7.5	7.8	11.3
Lived in area with community water fluoridation (%) [b]	92.3	81.8	91.3	97.5

[a] Difference between the levels of crowding; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of crowding; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation.

Table 4.6. Distribution of the <u>mandibular incisor alignment</u> by the dental caries status of the study participants at baseline (n = 211)

Characteristics	**Mandibular Incisor Alignment**			
	Spacing (n = 43)	**Ideal Alignment (n = 41)**	**Mild Crowding (n = 83)**	**Moderate/Severe Crowding (n = 57)**
Coronal Caries				
Mandibular anterior plaque index, mean ± SD [a]	4.0 ± 2.7	4.0 ± 3.5	4.3 ± 3.3	4.5 ± 2.9
Mandibular anterior calculus Index, mean ± SD [a]	5.4 ± 3.5	5.1 ± 4.1	6.2 ± 3.5	6.1 ± 3.7
Mandibular anterior coronal decayed surfaces, mean ± SD	0.2 ± 0.4	0.2 ± 0.6	0.2 ± 0.5	0.2 ± 0.6
Mandibular anterior coronal filled surfaces, mean ± SD	0.9 ± 1.7	1.2 ± 3.1	1.2 ± 3.2	1.2 ± 1.9
Mandibular anterior coronal decayed and filled surfaces, mean ± SD	1.0 ± 2.0	1.4 ± 3.2	1.4 ± 3.4	1.3 ± 2.2
Mandibular anterior coronal decayed teeth, mean ± SD	0.2 ± 0.4	0.2 ± 0.7	0.2 ± 0.4	0.2 ± 0.6
Mandibular anterior coronal filled teeth, mean ± SD [a]	0.6 ± 1.1	0.6 ± 1.2	0.7 ± 1.4	0.8 ± 1.2
Mandibular anterior coronal decayed and filled teeth, mean ± SD [a]	0.8 ± 1.3	0.8 ± 1.6	0.9 ± 1.6	1.0 ± 1.5
Root Caries				
Mandibular anterior root decayed surfaces, mean ± SD [a]	0.0 ± 0.0	0.05 ± 0.3	0.06 ± 0.2	0.04 ± 0.2
Mandibular anterior root filled surfaces, mean ± SD [a]	0.2 ± 0.7	0.05 ± 0.2	0.1 ± 0.5	0.2 ± 0.6
Mandibular anterior root decayed and filled surfaces, mean ± SD [a]	0.2 ± 0.7	0.1 ± 0.5	0.2 ± 0.6	0.2 ± 0.7
Mandibular anterior root decayed teeth, mean ± SD [a]	0.0 ± 0.0	0.05 ± 0.3	0.06 ± 0.2	0.04 ± 0.2
Mandibular anterior root filled teeth, mean ± SD [a]	0.2 ± 0.7	0.05 ± 0.2	0.1 ± 0.5	0.2 ± 0.6
Mandibular anterior root decayed and filled teeth, mean ± SD [a]	0.2 ± 0.7	0.1 ± 0.5	0.2 ± 0.6	0.2 ± 0.7
At least one root decayed and filled tooth in the mandibular anterior arch (%) [b]	14.6	5.0	14.3	13.2

[a] Difference between the levels of crowding; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of crowding; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation.

Table 4.7. Distribution of mandibular incisor irregularity by selected characteristics of the study participants at baseline (n = 211)

Characteristics	**Mandibular Incisor Irregularity**		
	No/Mild (n = 106)	**Moderate (n = 70)**	**Severe (n = 35)**
Age (y), mean ± SD	60.2 ± 6.6	60.5 ± 6.3	60.3 ± 7.7
Number of teeth remaining, mean ± SD	23.8 ± 3.3	24.0 ± 3.1	24.1 ± 3.0
Number of Medications used, mean ± SD	2.2 ± 1.9	2.1 ± 1.6	2.1 ± 1.5
Income [b]			
≤$14,999	29.8	40.3	35.3
$15,000–$24,999	49.0	44.8	44.1
≥$25,000	21.2	14.9	20.6
Educational Level (%) [b]			
High school or some college	29.3	20.0	17.1
College graduate	70.8	80.0	82.9
Smoking status (%) % [b]			
Nonsmoker	89.6	90.0	94.3
Smoker	10.4	10.0	5.7
Flossing frequency (%) [b]			
Never	39.6	38.6	25.7
At least once\month	60.4	61.4	74.3
Brushing frequency (%) [b]			
Once a week or less	63.2	71.4	68.6
Twice a week of more	36.8	28.6	31.4
Saliva (%) [b]			
Limited	7.5	4.4	5.7
Copious	92.5	95.6	94.3
Prophylaxis in past year (%)	80.2	82.3	82.9
Dental treatment in the past year (%) [b]	63.2	67.1	57.1
Use of fluoride toothpaste (%) [b]	95.2	94.3	100
Use of fluoride mouthwash (%) [b]	6.6	10.0	17.1
Lived in area with community water fluoridation (%) [b]	85.9	95.8	96.2

[a] Difference between the levels of crowding; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of crowding; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation.

Table 4.8. Distribution of mandibular incisor irregularity by the dental caries status of the study participants at baseline (n = 211)

Characteristics	**Mandibular Incisor Irregularity**		
	No/Mild (n = 106)	**Moderate (n = 70)**	**Severe (n = 35)**
Coronal Caries			
Mandibular anterior plaque index, mean ± SD	4.2 ± 3.1	4.1 ± 3.4	4.4 ± 2.8
Mandibular anterior calculus index, mean ± SD [a]	5.6 ± 3.6	5.8 ± 3.7	6.2 ± 4.0
Mandibular anterior coronal decayed surfaces, mean ± SD	0.2 ± 0.5	0.2 ± 0.5	0.2 ± 0.8
Mandibular anterior coronal filled surfaces, mean ± SD	1.2 ± 2.9	1.1 ± 2.6	1.0 ± 2.1
Mandibular anterior coronal decayed and filled surfaces, mean ± SD	1.4 ± 3.0	1.2 ± 2.8	1.2 ± 2.5
Mandibular anterior coronal decayed teeth, mean ± SD	0.2 ± 0.5	0.2 ± 0.5	0.2 ± 0.8
Mandibular anterior coronal filled teeth, mean ± SD	0.7 ± 1.3	0.8 ± 1.3	0.6 ± 1.0
Mandibular anterior coronal decayed and filled teeth, mean ± SD	0.9 ± 1.5	0.9 ± 1.6	0.8 ± 1.5
Root Caries			
Mandibular anterior root decayed surfaces, mean ± SD [a]	0.02 ± 0.1	0.06 ± 0.3	0.09 ± 0.3
Mandibular anterior root filled surfaces, mean ± SD [a]	0.1 ± 0.5	0.2 ± 0.6	0.1 ± 0.5
Mandibular anterior root decayed and filled surfaces, mean ± SD [a]	0.1 ± 0.5	0.3 ± 0.7	0.2 ± 0.5
Mandibular anterior root decayed teeth, mean ± SD [a]	0.02 ± 0.1	0.06 ± 0.3	0.09 ± 0.3
Mandibular anterior root filled teeth, mean ± SD [a]	0.1 ± 0.5	0.2 ± 0.6	0.1 ± 0.5
Mandibular anterior root decayed and filled teeth, mean ± SD [a]	0.1 ± 0.5	0.3 ± 0.7	0.2 ± 0.5
At least one root decayed and filled tooth in the maxillary anterior arch (%) [b]	9.4	15.7	14.3

[a] Difference between the levels of crowding; $P < 0.05$, based on analysis of variance.

[b] Difference between the levels of crowding; $P < 0.05$, based on the Chi-square statistic.

SD, standard deviation.

Table 4.9. Unadjusted and adjusted mixed/fixed effects estimates and 95% confidence intervals of the association between maxillary anterior incisor alignment and anterior sum of coronal decayed and filled surfaces, and anterior sum of coronal decayed and filled teeth (n = 211)

Coronal Caries Outcomes	**Alignment Status Beta Estimate (95% CI)**						
	Continuous Variables		**Categorical Variables**				
			Spacing (n = 97)		**Ideal (n = 60)**	**Crowding (n = 54)**	
	Unadjusted	Adjusted [a]	Unadjusted	Adjusted [a]	Reference	Unadjusted	Adjusted [a]
Maxillary anterior sum of coronal decayed and filled surfaces	-0.76 * (-1.16 to -0.35)	-0.72 * (-1.14 to -0.30)	-2.12 (-4.25 to 0.01)	-1.95 (-4.15 to 0.26)	-	0.74 (-1.69 to 3.17)	0.61 (-1.90 to 3.13)
Maxillary anterior sum of coronal decayed and filled teeth	-0.33 * (-0.46 to -0.20)	-0.30 * (-0.43 to -0.17)	-1.05 * (-1.73 to -0.36)	-0.93 * (-1.62 to -0.24)	-	0.22 (-0.56 to 1.01)	0.24 (-0.54 to 1.02)

* $P < 0.05$.

[a] Model adjusted for age, plaque score, calculus score, college education (yes/no), flossing (never/ever), brushing (≤1 times a day/ ≥2 times a day), salivary flow (limited/copious), income (low: ≤\$14,999; middle: \$15,000–\$24,999; high: ≥\$25,000), and number of remaining teeth in the anterior arch.

CI, confidence interval.

Table 4.10. Unadjusted mixed/fixed effects estimates and 95% confidence intervals of the association between maxillary anterior incisor irregularity and anterior sum of coronal decayed and filled surfaces, and anterior sum of coronal decayed and filled teeth (n = 211)

Coronal Caries Outcomes	**Irregularity Status Beta Estimate (95% CI)**			
	Continuous Variables	**Categorical Variables**		
		No/Mild (n = 146)	**Moderate (n = 43)**	**Severe (n = 22)**
	Unadjusted	Reference	Unadjusted	Unadjusted
Maxillary anterior sum of coronal decayed and filled surfaces	-0.15 (-0.57 to 0.27)	-	-1.03 (-1.24 to 3.31)	-1.07 (-4.07 to 1.94)
Maxillary anterior sum of coronal decayed and filled teeth	0.01 (-0.13 to 0.15)	-	0.41 (-0.33 to 1.16)	0.27 (-0.71 to 1.26)

* $P < 0.05$.

CI, confidence interval.

Table 4.11. Unadjusted mixed/fixed effects estimates and 95% confidence intervals of the association between mandibular anterior incisor alignment and anterior sum of coronal decayed and filled surfaces, and anterior sum of coronal decayed and filled teeth (n = 211)

Coronal Caries Outcomes	**Alignment Status Beta Estimate (95% CI)**				
	Continuous Variables	**Categorical Variables**			
		Spacing (n = 43)	**Ideal (n = 41)**	**Mild Crowding (n = 83)**	**Moderate/Severe Crowding (n = 57)**
	Unadjusted	Unadjusted	Reference	Unadjusted	Unadjusted
Mandibular anterior sum of coronal decayed and filled surfaces	0.07 (-0.10 to 0.24)	0.19 (-1.15 to 1.52)	-	0.23 (-0.94 to 1.40)	-0.05 (-1.31 to 1.21)
Mandibular anterior sum of coronal decayed and filled teeth	0.02 (-0.06 to 0.10)	0.20 (-0.44 to 0.83)	-	0.23 (-0.33 to 0.78)	0.23 (-0.37 to 0.83)

* $P < 0.05$.
CI, confidence interval.

Table 4.12. Unadjusted mixed/fixed effects estimates and 95% confidence of the association between mandibular anterior incisor irregularity and anterior sum of coronal decayed and filled surfaces, and anterior sum of coronal decayed and filled teeth (n = 211)

Coronal Caries Outcomes	**Irregularity Status Beta Estimate (95% CI)**			
	Continuous Variables	**Categorical Variables**		
		No/Mild (n = 106)	**Moderate (n = 70)**	**Severe (n = 35)**
	Unadjusted	Reference	Unadjusted	Unadjusted
Mandibular anterior sum of coronal decayed and filled surfaces	-0.15 (-0.57 to 0.27)	-	-1.03 (-1.24 to 3.31)	-1.07 (-4.07 to 1.94)
Mandibular anterior sum of coronal decayed and filled teeth	0.01 (-0.13 to 0.15)	-	0.41 (-0.33 to 1.16)	0.27 (-0.71 to 1.26)

* $P < 0.05$.
CI, confidence interval.

Table 4.13. Unadjusted odds ratio and 95% confidence intervals from the generalized estimation equation analyses of the association between maxillary anterior incisor alignment and the occurrence of at least one root decayed and filled tooth in the maxillary anterior arch (n = 211)

Root Caries Outcomes	**Alignment Status Odds Ratio (95% CI)**			
	Continuous Variables	**Categorical Variables**		
		Spacing (n = 97)	**Ideal (n = 60)**	**Crowding (n = 54)**
	Unadjusted	Unadjusted	Reference	Unadjusted
At least one root decayed and filled tooth in the maxillary anterior arch	0.94 (0.83 to 1.05)	0.82 (0.46-1.44)	-	1.32 (0.72-2.41)

* $P < 0.05$.
CI, confidence interval.

Table 4.14. Unadjusted odds ratio and 95% confidence intervals from the generalized estimation equation analyses of the association between maxillary anterior incisor irregularity and the occurrence of at least one root decayed and filled tooth in the maxillary anterior arch (n = 211)

Root Caries Outcomes	**Irregularity status odds ratio (95% CI)**			
	Continuous Variables	**Categorical Variables**		
		No/Mild (n = 146)	**Moderate (n = 43)**	**Severe (n = 22)**
	Unadjusted	Unadjusted	Reference	Unadjusted
At least one root decayed and filled tooth in the maxillary anterior arch	1.03 (0.92-1.16)	-	1.09 (0.61-1.94)	1.88 (0.81-4.37)

* $P < 0.05$.
CI, confidence interval.

Table 4.15. Unadjusted odds ratio and 95% confidence intervals from the generalized estimation equation analyses of the association between mandibular anterior incisor alignment and the occurrence of at least one root decayed and filled tooth in the mandibular anterior arch (n = 211)

Root Caries Outcomes	**Alignment status odds ratio (95% CI)**				
	Continuous Variables	**Categorical Variables**			
		Spacing (n = 43)	**Ideal (n = 41)**	**Mild Crowding (n = 83)**	**Moderate/Severe Crowding (n = 57)**
	Unadjusted	Unadjusted	Reference	Unadjusted	Unadjusted
At least one root decayed and filled tooth in the mandibular anterior arch	1.02 (0.90-1.16)	2.81 (0.92-8.7)	-	2.38 (0.83-6.78)	2.04 (0.67-6.19)

* $P < 0.05$.
CI, confidence interval.

Table 4.16. Unadjusted odds ratio and 95% confidence intervals from the generalized estimation equation analyses of the association between mandibular anterior incisor irregularity and the occurrence of at least one root decayed and filled tooth in the mandibular anterior arch (n = 211)

Root Caries Outcomes	**Irregularity status odds ratio (95% CI)**			
	Continuous Variables	**Categorical Variables**		
		No/Mild (n = 106)	**Moderate (n = 70)**	**Severe (n = 35)**
	Unadjusted	Unadjusted	Reference	Unadjusted
At least one root decayed and filled tooth in the mandibular anterior arch	1.06 (0.91-1.23)	-	1.35 (0.68-2.67)	1.17 (0.46-3.02)

* $P < 0.05$.
CI, confidence interval.

CUMULATIVE REFERENCES

List of Abbreviated Journal Titles:

Acta Odontol Scand	Acta Odontologica Scandinavica
Am J Orthod	American Journal of Orthodontics
Am J Orthod Dentofacial Orthop	American Journal of Orthodontics and Dentofacial Orthopedics
Angle Orthod	The Angle Orthodontist
Aust Orthod J	Australian Orthodontic Journal
Br Dent J	British Dental Journal
Bull World Health Organ	Bulletin of the World Health Organization
Caries Res	Caries Research
Clin Oral Investig	Clinical Oral Investigations
Community Dent Health	Community Dental Health
Community Dent Oral Epidemiol	Community Dentistry and Oral Epidemiology
Compend Contin Educ Dent	Compendium of Continuing Education in Dentistry
Crit Rev Oral Biol Med	Critical Reviews in Oral Biology and Medicine
Curr Opin Periodontol	Current Opinion in Periodontology
Dental Press J Orthod	Dental Press Journal of Orthodontics
East Afr Med J	East African Medical Journal
Endod Dent Traumatol	Endodontics and Dental Traumatology

Eur J Oral Sci	European Journal of Oral Sciences
Eur J Orthod	European Journal of Orthodontics
Int Dent J	International Dental Journal
Int J Adult Orthodon Orthognath Surg	The International Journal of Adult Orthodontics and Orthognathic Surgery
Int J Aging Hum Dev	International Journal of Aging and Human Development
Int J Dent	International Journal of Dentistry
J Am Dent Assoc	The Journal of the American Dental Association
J Can Dent Assoc	Journal of the Canadian Dental Association
J Clin Pediatr Dent	Journal of Clinical Pediatric Dentistry
J Clin Periodontol	Journal of Clinical Periodontology
J Dent	Journal of Dentistry
J Dent Educ	Journal of Dental Education
J Dent Res	Journal of Dental Research
J Evid Based Dent Pract	Journal of Evidence-Based Dental Practice
J Oral Rehabil	Journal of Oral Rehabilitation
J Orofac Orthop	Journal of Orofacial Orthopedics
J Periodontol	Journal of Periodontology
J Public Health Dent	Journal of Public Health Dentistry
JAMA Otolaryngol Head Neck Surg	JAMA Otolaryngology - Head and Neck Surgery
Pediatr Dent	Pediatric Dentistry
Periodontol 2000	Periodontology 2000

Spec Care Dentist	Special Care in Dentistry
Trans Eur Orthod Soc	Transactions of the European Orthodontic Society

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