Estimation of the rate of tooth wear in permanent incisors: a cross-sectional digital radiographic study

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SUMMARY This study used conventional digital radiography to estimate the rate of tooth wear (TW) of maxillary and mandibular central incisors based on a cross-sectional study design. The crown length of 1239 permanent maxillary and mandibular central incisors from 346 persons (age groups: 10, 25, 40, 55 and 70 years) were measured by three calibrated dentists. Study teeth were intact incisally, had clearly visible incisal edges and cementoenamel junctions and had natural tooth antagonists. Measures were based on digital radiographic images (N = 666) archived in MiPACS within the electronic health record (axiUm®) from the College of Dentistry patient database. Incisor crown length decreased at a linear rate in both arches over the 60 years represented by the age groups. The average crown length for maxillary incisors in the youngest age group was 11.94 mm, which decreased by an average of 1.01 mm by median age 70. For mandibular incisors, the average crown length in the youngest age group was 9.58 mm, which decreased by an average of 1.46 mm in the oldest age group. Males and females showed similar rates of TW. Regardless of age, females demonstrated smaller mean crown height for maxillary incisors than males (P < 0.0001). Measures by the examiners demonstrated good agreement, with an interclass correlation coefficient of 0.869 and an average intra-examiner correlation of 99.5%, based on repeated measurements (n = 100). TW was estimated to average 1.01 mm for maxillary central incisors and 1.46 mm for mandibular central incisors by age 70 years.

KEYWORDS: dental disease, age groups, dental occlusion, incisor, tooth attrition, tooth wear

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Introduction

Tooth wear (TW) is generally assumed to be a normal and expected consequence of ageing. Despite its prevalence and significant association with age, the rate of TW in humans is not clearly defined. In a study of 585 adults living in Sweden, Hugoson et al. (1) observed increasing severity of TW associated with age using a TW index (TWI). The authors observed wear on incisal and occlusal surfaces that increased from 13.6% at age 20 years to 24.1% at age 50 years. Greater severity of TW was observed in persons over age 50 (1). Findings of unacceptable levels of enamel wear on deciduous teeth (2–6) and on the occlusal surfaces of permanent teeth that slowly increases with age have been reported in a few studies and reviews (7–15). However, the literature is lacking in precise measures of the annual rate of enamel wear and dentin exposure in large numbers of teeth over significant periods of time. Moreover, our knowledge of the rate of TW (e.g. millimetre of wear per year) remains imprecise because of limited inclusion of dentate elderly persons who

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often exhibit the greatest amounts of wear, and it is difficult to measure longitudinally the same patient for long periods of time. Thus, the aim of this study was to apply a novel approach, using conventional digital radiography, to assess the rate of TW using a cross-sectional design of a large population of patients aged 10 years to 73 years by measuring the crown length of more than 1000 maxillary and mandibular central incisors. The null hypothesis was that the mean crown length in the younger population would be similar to that observed in the older population.

Methods

This study was conducted at the University of Kentucky, College of Dentistry (UKCD), Lexington, Kentucky. Participants were selected based on age, and the availability of digital radiographic images taken between August, 2010 and February 1, 2014 using, XCP instruments, Schick sensors and a standardised paralleling technique. This technique has been shown to be highly repeatable and accurate for measurements of actual tooth length (16, 17). All images were stored in MiPACS in the electronic health record (EHR) (axiUm). The institutional review board approved the study, and all procedures were performed in accordance with the guidelines set out by the Declaration of Helsinki. The EHR database was queried for patients who had received radiographic imaging using the treatment codes: D0210 (full mouth X-rays), D0220A (single X-ray), D0230A (additional X-ray), D0220B (ortho anterior periapicals), D0220P (single X-ray/Pedo-Ortho) and D0220W (walk-in urgent care periapical). The query resulted in 3864 periapical radiographic images from which duplicates were removed, and participants were selected based on age. Five groups were targeted: 10, 25, 40, 55 and 70 years of age, with an equal percentage being male and female. Inclusion criteria were as follows: minimum age of 10 years, complete and clear image of the maxillary and mandibular central incisors that included the incisal edge and cementoenamel junction (CEJ), the absence of restoration of the incisal surface of central incisors, the presence of an opposing natural tooth antagonist without restoration and images that lacked distortion (i.e. elongation or foreshortening). Exclusion criteria were images that failed to show the entire crown of the central incisors and clearly delineate the CEJ, or demonstrated poor contrast, elongation or foreshortening as evident by a separation of the facial and lingual CEJ of more than 0.5 mm, central incisor containing a restoration or caries involving the incisal edge, central incisor containing a class V (cervical) restoration, missing opposing central incisor or opposing central incisor with a restoration. In the youngest age group, at least 200 maxillary and 200 mandibular teeth were measured to establish an accurate baseline. In the remaining groups, at least 100 maxillary and 100 mandibular incisors were measured.

Data analysis

Data were collected based on measurements of the maxillary central incisors and mandibular central incisors taken from digital periapical radiographs of the patients described above. Three calibrated raters, who were experienced clinicians (i.e. each having more than 25 years of clinical experience), separately measured the height of the crown of the central incisors in a dark room using the MiPacs software (Medicor Imaging, Charlotte, NC, USA) and recorded the measurements. Digital periapical radiographs were selected and enlarged to 8.5 × 5.75 inch on the computer screen monitor. At this image size, line detail remained clear in all images. A digital ruler within MiPacs was utilised to measure the height of the crown of the tooth (Fig. 1) by measuring the long axis of the tooth in millimetre from the mid-point of the incisal edge to the mid-facial of the CEJ. Delimitation of the incisal edge and CEJ was performed by adjusting the contrast and using the magnification tool, as needed. Delimitation was enhanced, when needed, by observing the crestal alveolar bone and allowing at least 1.5 mm distance between the bone height and the CEJ. As a result of these methods, in all instances, the incisal edge and CEJ were discerned. From the medical and dental history of each participant, the following information was recorded: age, gender, eating disorders, bruxism,
gastric reflux, sleep apnoea and the use of alcohol and tobacco products. Race was not included in the EHR of axiUm®; thus, race was not recorded.

To estimate the agreement amongst raters, an analysis of variance was constructed with fixed effects raters (three raters), tooth (each of the maxillary and mandibular central incisors) and the interaction between raters and tooth and random effects due to participant, raters by participant, tooth by participant and measurement error. As some raters did not rate all of the teeth (missing ratings for some raters on some of the teeth), a linear mixed model was constructed to estimate the four variance components corresponding to the random effects. The interclass correlation coefficient (ICC) that measured the correlation between assessments of TW by any two of the raters was determined. The intra-rater ICC was based on 31 randomly selected subjects in which 100 incisors were measured in triplicate by each rater. To determine how the measurements on a tooth varied amongst the raters, the coefficient of variation (CV) was constructed per tooth and then averaged across all teeth.

To investigate how age affected TW, the TW ratings for a given tooth were first averaged across the raters who examined that tooth and provided a measurement. Then, a multiple linear regression model was constructed in which this average TW rating was regressed on the participant’s age, gender, and the interaction between age and gender. This model assumed that TW declines linearly with age for each gender. A separate model was constructed for each tooth number and then for the maxillary and mandibular teeth. As the interaction between age and gender was not significant in any of these regression models, this term was dropped from the final models. Statistical significance was determined at the 0.05 level.

Results

Study population

Based on the inclusion and exclusion criteria, 346 participants (172 males and 174 females) were studied. The characteristics of the study participants are presented in Table 1 categorised by age group, gender, number of participants, radiographs evaluated, median age and age range. Race was not recorded in axiUm®; thus, race was not included in the final analysis. The target ages for each of the five groups were 10, 25, 40, 55 and 70 years, with the median closely approximating those targets. Age group 1 was the largest group consisting of 109 participants. Between 55 and 61 participants were evaluated in each of the other four groups.

TW of the maxillary and mandibular central incisors

Two thousand eighty-two radiographs were reviewed by one examiner (CSM) to determine whether each image met the inclusion and exclusion criteria. From these, 672 radiographs were selected for evaluation, and six more images were excluded due to tooth imaging issues. Three examiners independently reviewed the 666 radiographs which accurately imaged the central incisors and the CEJs. As a result, 1239 central incisors that had an opposing natural tooth antagonist with visible CEJs were measured (Fig. 2). Excellent agreement between the measures recorded by the three raters was observed, with an overall ICC of 0.869, an average intra-examiner correlation of 99.5%, and a CV amongst the three raters of 3.36%.

Figure 3 displays the crown height measurements for all maxillary central incisors examined by age.
A fairly constant and linear decrease in crown height as age increased is observed, with no significant difference in the left or right side noted. In this study, the average crown height for the maxillary incisors in age group 1 was 11.94 mm, which decreased to 10.93 mm in age group 5; a loss of 1.01 mm. A similar trend was seen in the mandibular incisors of all five age groups. However, wear of the mandibular incisors was greater over time compared to the maxillary incisors. Here, the average tooth height for the mandibular incisors in age group 1 was 9.58 mm, which decreased to 8.12 mm in group 5; a loss of 1.46 mm. Together, the data estimate that the average 10-year loss of incisal tooth structure is 0.17 mm for maxillary central incisors and 0.25 mm for mandibular central incisors. Of note, in the oldest age group, 18% females and 20% males demonstrated ≥2 mm of TW compared with the crown height of the 11-year age group.

Table 1. Characteristics of the five groups as categorised by age and gender

<table>
<thead>
<tr>
<th>Group no.</th>
<th>Gender</th>
<th>Number of participants</th>
<th>Total participants</th>
<th>Number of radiographs</th>
<th>Number of teeth</th>
<th>Median, years</th>
<th>Age range, years</th>
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</thead>
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<tr>
<td>1</td>
<td>F</td>
<td>55</td>
<td>109</td>
<td>218</td>
<td>407</td>
<td>11.5</td>
<td>10–13</td>
</tr>
<tr>
<td>1</td>
<td>M</td>
<td>54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>29</td>
<td>61</td>
<td>112</td>
<td>198</td>
<td>25</td>
<td>22–28</td>
</tr>
<tr>
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<td>M</td>
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<td></td>
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<tr>
<td>3</td>
<td>F</td>
<td>32</td>
<td>61</td>
<td>112</td>
<td>200</td>
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<td>37–43</td>
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<td>4</td>
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<td>F</td>
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<td>60</td>
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<td>223</td>
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<td>M</td>
<td>30</td>
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</tbody>
</table>

Fig. 2. Example of central incisors measured in each age group.

Fig. 3. Estimated tooth wear rate of maxillary central incisors and mandibular central incisors.
TW of central incisors for males versus females

We next examined TW by gender. Here, we combined the crown length of the four central incisors for each gender and calculated the overall mean. As shown in Fig. 4, males and females showed a similar rate of TW, with females demonstrating smaller crown height for maxillary incisors regardless of age \((P < 0.0001)\). Also, crown height for the mandibular incisors trended towards being smaller in females \((P = 0.057)\).

Discussion

Aspects of TW have been examined in previous studies, but the rate of TW has not been fully characterised. In past studies, the prevalence and severity of TW have been documented; \((1, 10–15)\) however, the rate at which it occurs in permanent teeth has been inexact as a result of different teeth being studied, lack of older participants, lack of standardised and universally accepted methods for measuring TW and lack of long-term prospective studies \((4, 13, 18)\). To address the age consideration, we conducted a cross-sectional study where the crown length of the permanent central incisors of five age groups \((i.e. \text{median 11.5 to 70 years})\) was measured using conventional digital radiographic images. Digital radiographic images were used with knowledge that digital ruler measurements are relatively accurate \((i.e. \text{within 0.14 mm})\) compared with actual tooth crown measures when a standardised paralleling technique is employed \((16, 17)\). Further, the accuracy of the measures was enhanced by including only central incisors where the reference points \((i.e. \text{CEJ and incisal edge})\) were clearly visible, as this has been documented to be another potential source of error \((19)\). To our knowledge, this is the first study in the literature to quantify the rate of TW using conventional digital radiography and measures of more than 1200 teeth.

In this study of 346 persons, the radiographically determined crown length of the mandibular and maxillary central incisors was found to decrease over time. Maxillary central incisors were greatest in crown length in the 11-year age group, but were diminished by 1.01 mm by age 70. Similarly, mandibular central incisors were greatest in crown length in the youngest group and were diminished by 1.46 mm by age 70. Crown length was observed to decrease each 15-year age group interval. Overall, the average 10-year loss of tooth height was 0.17 mm for the maxillary centrals and 0.25 mm for the mandibular centrals.

Our finding of increased TW with increased age is in accordance with several studies. Smith and Robb \((8)\) observed the prevalence of worn tooth surfaces in their study of 1007 subjects, with 97% of the entire cohort exhibiting TW. Although their assessments of severity using a TWI also showed that TW tends to increase with age, precise measures of TW were not reported. In two studies, Hugoson \(et\ al.\) measured the severity of wear on 1112 individuals using a TWI scale, a relatively imprecise measure of wear, and found TW increased from 13.6% at 20 years to 24.1% at 50 years of age \((1, 11)\). Similarly, in a retrospective study using study models, Bartlett measured severity of wear on 17 984 tooth surfaces using a TWI and observed slow progression of TW, but stated that wear is not inevitable with age \((15)\). A systematic review reported significant TW of 3% at age 20 and 17% by age 70 \((10)\). However, in another systematic review of 32 408 younger persons \((7–16.5\) years of age), the prevalence of TW resulting in dentin exposure was not linearly associated with age \((2)\). The mixed results amongst these studies and others\((1, 4, 20–26)\) could be attributed to several factors including study design, sample size, age of participants, ethnicity, teeth selected, type of tooth antagonist, number of tooth surfaces measured, type of measures recorded, TWI used, influences of erosion, abrasion, bite force, and experience and calibration of the examiners \((9, 27–33)\).

A significant aim of this study was to estimate the rate of TW, because there is scant information in the literature on this subject. We found only three
comparable studies. In an *in vivo* study of enamel TW on 21 subjects over a period of 2 years, a yearly attrition rate of 29 microns (0.029 mm) on molars and 15 microns (0.015 mm) on pre-molars was reported (7). A slower rate of wear, 0.04 mm³ by volume and 10 microns (0.015 mm) by depth of posterior teeth was reported in 18 adults over 2 years using digitised study models (15). In the third study, less than 15 microns of median TW was observed in the majority of 63 adults after 12 months, although 13% of participants had median TW greater than 15 microns (14). As these studies only followed a limited number of patients (n = 102) for 2 years or less, it is difficult to make conclusions on the long-term rate of wear as age increases. However, in our study, the annual TW was 0.017 mm in maxillary central incisors and 0.025 mm in mandibular central incisors, which was similar to these prior reports.

Our findings demonstrate that the rate of TW for males and females was similar. Previous studies have reported that men had higher TW scores than women; (1, 20, 22, 23, 25, 34) however, this has not been a consistent reporting (11). In past studies, incisal wear as well as occlusal wear of posterior teeth was measured in these cohorts. This could explain the difference. Other factors such as geographical differences, different habits and other aetiological factors may also be explanatory.

The results of this study are predicated on measurements of tooth height made from digital periapical radiographs by three dental faculty members. Strengths of the study include: (i) each examiner had over 25 years of clinical experience (i.e. endodontics, oral and maxillofacial radiology, and general dentistry), (ii) the ICC value was 0.869 suggesting excellent agreement in the measures recorded by the three examiners, (iii) the intra-examiner correlation was very high (99.5%) suggesting that the measures were very repeatable, (iv) a large sample size was used that allowed for inclusion of a significant number of younger and older individuals, (v) numerous digital periapical radiographs were available that allowed for the selection of teeth with opposing natural dentition, so the measurements made favoured that the observation was natural physiological TW (i.e. attrition) and (vi) digital radiographs provide accurate measures of crown length when the paralleling technique is employed (16, 17). However, the use of conventional digital radiography has limitations. Although the authors excluded radiographs of poor diagnostic quality and those that demonstrated foreshortened or elongated tooth structures to minimise distortion per the inclusion and exclusion criteria, some images may not have been perfectly parallel with the sensor. Thus, measurement errors may have occurred in an undefined percentage of cases due to the lack of use of a bite block alignment positioner (35). Also, it is unclear whether the teeth studied made occlusal contact with their antagonist. Finally, in as much as the EHR was incomplete with respect to other aetiological factors and race we cannot state what role these factors may have played, nor can we state that the wear measured was due to attrition.

**Conclusion**

Based on a cross-sectional study design and digital radiographic measures, TW was estimated to average 1.01 mm for maxillary central incisors and 1.46 mm for mandibular central incisors by 70 years of age.

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**Conflict of interest**

The authors report no conflict of interests related to this study.

**References**


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