Age estimation from structural changes of teeth and buccal alveolar bone level

K.K. Koh, J.S. Tan, P. Nambiar,*, Norliza Ibrahim, Sunil Mutalik, Muhammad Khan Asif

Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia
Department of Oral and Maxillofacial Clinical Sciences, Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia
Faculty of Dentistry, International Medical University, Malaysia

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ABSTRACT

Forensic odontology plays a vital role in the identification and age estimation of unknown deceased individuals. The purpose of this study is to estimate the chronological age from Cone-Beam Computed Tomography (CBCT) images by measuring the buccal alveolar bone level (ABL) to the cemento-enamel junction and to investigate the possibility of employing the age-related structural changes of teeth as studied by Gustafson. In addition, this study will determine the forensic reliability of employing CBCT images as a technique for dental age estimation. A total of 284 CBCT images of Malays and Chinese patients (150 females and 134 males), aged from 20 years and above were selected, measured and stages of age-related changes were recorded using the i-CAT Vision software. Lower first premolars of both left and right side of the jaw were chosen and the characteristics described by Gustafson, namely attrition, secondary dentine formation and periodontal recession were evaluated. Linear regression analysis was performed for the buccal bone level and the R values obtained were 0.85 and 0.82 for left and right side respectively. Gustafson's characteristics were analysed using multiple regression analysis with chronological age as the dependent variable. The results of the analysis showed R values ranged from 0.44 to 0.62. Therefore it can be safely concluded that the buccal bone level highly correlated with the chronological age and is consequently the most suitable age-related characteristic for forensic age estimation.

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1. Introduction

Age estimation of living and deceased individuals is imperative in both forensic and clinical work. As there is global increase in unidentified corpses and skeletons, it is important to ascertain the identity of a dead person from ethical, legal and criminal perspectives.1-4 Besides, cases of age estimation in living individuals have increased recently due to increased migration from areas of conflict.5 Due to this demand, several skeletal and dental methods for assessing age have been developed to ascertain the biological age of an individual and therefore providing an estimate of his/her chronological age.

However, age estimation from teeth is of particular importance because they are highly resistant to mechanical, chemical, or physical impacts and time6-8 and thus, aid greatly in forensic identification work of decomposed remains. It can also be examined directly in living individuals.9 In recent years, radiographs or images have become one of the most important and reliable methods in dental age determination, especially with the more advanced imaging techniques.10 This includes Computer Tomography and Magnetic Resonance Imaging which provide 3-dimensional view of a human structure. With the introduction of Cone-Beam Computed Tomography (CBCT), even general dental practitioners were recording their patients’ dentition in their own dental clinics.

In 1950, Gustafson became the first to introduce a scientific method for age estimation using six age-related changes in tooth structure.11 The six characteristics are regressive changes such as secondary dentine formation, periodontal recession, attrition, apical translucency, cementum apposition and external root resorption. Matsikidis et al.12 reported that the characteristics studied by Gustafson (except apical translucency) in relation to extracted
ground teeth can also be determined using dental films. Subsequently, multiple studies have been conducted with different dental radiographic techniques employing the characteristics studied by Gustafson to aid in age determination. Olze et al.13 has carried out an investigation to study the reliability of the characteristics employing dental panoramic tomographs. Kvaal et al.14 introduced the methods of correlations between chronological age and ratios of height and width of teeth and the pulp cavities as measured on dental radiographs for age estimation. In recent years, Kvaal's method of measuring the ratios of pulp chamber compared to total tooth length have also been conducted with dental panoramic tomographs15 and microfocus X-ray computer tomographs.16 However, the studies on microfocus X-ray computer tomograph are of questionable reliability due to the limited number of samples and the studies were exclusively on extracted teeth.

Interestingly, Micro-CT is the more detailed imaging procedure with more specific information which enabled quantitative evaluation of tooth from a three-dimensional view. Vandevooort et al.17 described a method that uses the three-dimensional measurements by performing regression analysis for the relationship between age and the volume ratio of the pulp cavity in different types of single rooted teeth. In addition, Aboshi et al.18 reported a method based on the calculation of ratio of the three-dimensional volume of the pulp chamber compared to the total tooth of lower premolars using microfocus X-ray computed tomography. Maret et al.19 have reported the possibility and utilization of CBCT machine in age determination. They proved that with the help of CBCT images, multiple regression analysis was performed - including quantitative volumetric measurement of various parts of each tooth were useful significant variables for dental age estimation in living subjects. Multiple regression analysis requires a constitution of a large sample sizes and this is possible with CBCT images.

This present study investigated the use of CBCT as a modality in forensic age determination based on measurement of buccal bone level to cemento-enamel junction. Buccal bone level is an important characteristic for age estimation as it can be measured even in decomposed bodies. Besides that, this study also reassessed whether the characteristics described by Gustafson, namely attrition, secondary dentine formation and periodontal recession can be used appropriately for forensic age estimation employing this scanning modality images.

2. Materials and methods

The design of this study was a retrospective cross-sectional study of CBCT images obtained from the Oral and Maxillofacial Imaging Division, Faculty of Dentistry, University of Malaya. One hundred and fifty female and 134 male images of Malays and Chinese were selected from the database (recordings) in the i-CAT imaging system (Imaging Sciences International Inc. Hatfield, PA, USA). All images were taken following a standardized protocol for patient positioning, exposure parameter setting (120 kVp, 3–7 mA, 20 s) and image acquisition at 0.3 mm voxel size. The scans were from the year 2007–2014 and the images obtained were manipulated with the i-CAT Vision software. Table 1 shows the number of cases per age group. The investigation protocol described herein was approved by the Ethics Committee of Faculty of Dentistry, University of Malaya (Reference number: DF DP1402/0040(U)).

A pilot study of 20 randomly selected CBCT images were carried out where the lower premolars were assessed with regard to the position of buccal bone level, characteristics of attrition, secondary dentine formation and periodontal recession. The exclusion criteria for each characteristic described by Gustafson were drawn from the recommendations suggested by Matsikidis et al.12 with additional exclusion criteria for bone level measurements obtained from this pilot study (Table 2). It was determined from this pilot study that the lower second premolar had a high degree of variability - such as being missing, impacted and rotated. For this reason, lower first premolars of both left and right side of the jaw were selected as the subjects of this study.

Although 300 CBCT scans were selected from the database, only 284 images were suitable as they fulfilled the selection criteria. The registration number, gender, race, date of birth and date when the images were taken were recorded. Measurements were carried out by two different observers. Data obtained were recorded and statistically analysed using SPSS 12.0.1 software for Windows. Gustafson's criteria of attrition, secondary dentine formation and periodontal recession were measured by slicing the images sagitally in the centre of the tooth and classified in accordance to the stages reported by Olze et al.13 Figs. 1–3 show the images for each stage mentioned below:

### Attrition

Stage 0: No attrition
Stage 1: Beginning attrition with loss of cusp tips
Stage 2: Attrition reaching into dentine
Stage 3: Attrition reaching into dentine with opening of pulp cavity

### Secondary dentine formation

Stage 0: Pulp horn reaches to above crown equator*
Stage 1: Pulp horn reaches at maximum to crown equator*
Stage 2: Pulp horn exceeds enamel-cementum boundary and falls short to crown equator*
Stage 3: Pulp horn reaches at maximum to enamel-cementum boundary
  *crown equator refers to the mid-point of crown length measured from cervical line to the highest cusp tip.

### Periodontal recession

Stage 0: No periodontal recession
Stage 1: Periodontal recession into cervical root third
Stage 2: Periodontal recession into middle root third
Stage 3: Periodontal recession into apical root third

Bone level measurements were carried out by slicing the images.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Number of subjects</th>
</tr>
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<tbody>
<tr>
<td>20–29</td>
<td>108</td>
</tr>
<tr>
<td>30–39</td>
<td>69</td>
</tr>
<tr>
<td>40–49</td>
<td>55</td>
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<tr>
<td>50–59</td>
<td>31</td>
</tr>
<tr>
<td>60 and above</td>
<td>21</td>
</tr>
<tr>
<td>TOTAL</td>
<td>284</td>
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### Table 1

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</tr>
<tr>
<td>TOTAL</td>
<td>284</td>
</tr>
</tbody>
</table>

### Table 2

| Exclusion criteria according to Matsikidis et al.12 with additional criteria for bone level. |
|---------------------------------|---------------------------------|
| Crowned tooth or bridge abutment, filling, partial crown or inlay, post and core restoration, carious lesion, root filling, infected tooth, impacted tooth, retained root, apexectomy, attrition, secondary dentine formation, periodontal recession, bone level. |

C crowned tooth or bridge abutment, F filling, partial crown or inlay, P post and core restoration, CL carious lesion, RF root filling, IF infected tooth, IM impacted tooth, R retained root, AE apexectomy, AT attrition, SE secondary dentine formation, PE periodontal recession, BL bone level.
coronally and measurements were made from cemento-enamel junction to the highest point of buccal bone. Fig. 4 illustrates how the measurements were recorded from the images.

2.1. Statistical analyses

The correlation between chronological age and individual characteristics were studied with the aid of Multiple Regression Analysis (MRA) and Linear Regression Analysis (LRA). Chronological age and individual characteristics formed the dependent and independent variables respectively. Stepwise method was used to ensure that only influencing variables were included in the model for MRA.

LRA was used to analyse both Gustafson’s characteristics and bone level. However, MRA was employed only for Gustafson’s characteristics. Pearson correlation was used to determine whether the value obtained from the left premolar is comparable to the value obtained from the right premolar. The strength and accuracy of the data in determining chronological age were studied with Pearson’s correlation coefficient, $R$ and coefficient of determination, $R^2$. $R$ measures the strength and the direction of a linear relationship between two variables while $R^2$ explain how well the regression line obtained represents the data.20

Meanwhile, potential multicollinearities between the independent variables in MRA were determined by studying the Variance Inflation Factor (VIF). In MRA, it is important to ensure that one independent variable is not affecting another independent variable and for this study, VIF value of more than 4 is considered to be critical multicollinearity.13

The inter-observer reliability and intra-observer reliability for
the characteristics of attrition, secondary dentine formation and periodontal recession were studied by k-statistics while bone level reliability was determined by concordance correlation coefficient.

3. Results

The statistical analyses performed showed that there were no significant intra-observer and inter-observer differences in the 20 randomly selected images which were re-evaluated. Data obtained shows high correlation level of 98% among both observers. Pearson’s Correlation (Table 3) shows that the value obtained from the right side of jaw is positively correlated with the left side of jaw. However, left side is more highly correlated to the chronological age.

Fig. 5 and Fig. 6 show the linear graph of chronological age in relation to buccal bone level. From the graphs, it is observed that bone levels measured for the younger age group (from 20 to 40 years of age) showed less dispersion from the linear line compared to older age group. Interestingly, the buccal bone level measured increased linearly with advancing age.

The formula obtained for dental age estimation based on the characteristics of buccal bone level, attrition, secondary dentine formation and periodontal recession were presented in Table 4 and Table 5 respectively. R value for attrition alone is higher compared to the one in MRA. Interestingly, the characteristic of attrition seems to be a stronger predictor of age when compared to secondary dentine, periodontal recession and also when all three characteristics were combined. The value of R obtained for Gus-tafson’s characteristics ranged from 0.44 to 0.62. The R value obtained from buccal bone level was of the highest with value 0.85 and 0.82 for left and right side respectively.

4. Discussion

The CBCT images included in this study were taken from patients’ database in the Faculty of Dentistry, University of Malaya who had agreed to the scanning procedure. The assumption made was that, all these subjects represent a “normal population”. However, the “lower-socioeconomic group” might be over-represented as patients visiting this government-based dental

![Image before measurement](image1.png) ![Image after measurement](image2.png)

**Fig. 4.** Bone level measurement.

![Linear graph of chronological age versus buccal bone level](graph.png)

**Fig. 5.** Linear graph of chronological age versus buccal bone level (left).

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Pearson’s correlation of value obtained from buccal bone level (left) and buccal bone level (right).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age</td>
</tr>
<tr>
<td>Age</td>
<td>1.000</td>
</tr>
<tr>
<td>Buccal Bone Level (Left)</td>
<td>0.816</td>
</tr>
<tr>
<td>Buccal Bone Level (Right)</td>
<td>0.797</td>
</tr>
</tbody>
</table>
The stages of attrition, secondary dentine formation and periodontal recession were not highly correlated with chronological age as the value of the correlation coefficient, \( R \) ranged from 0.44 to 0.62. This value of \( R \) was lower from the results obtained by Olze et al.\(^{13}\) as they recorded \( R \) value of 0.65–0.73 after evaluating dental panoramic tomographs (DPT). The lower correlation in CBCT may be due to the problem with “slicing” of the image (0.3 mm voxel size) where there is a possibility of variability in the area of the tooth being sliced. Meanwhile, images in DPT were 2-dimensional which do not require “slicing” of images and thus providing “whole” morphology of the tooth comprising all the “slices”. Buccal bone level was highly correlated with chronological age with \( R \) value of 0.85 for left side and 0.82 for right side. From the data obtained, it could be concluded that bone level decreases with advancing age. This may be due to bone resorption that occurs as we grow older. Besides, passive eruption of teeth will also cause the “readings” for bone level measured to increase due to attrition of teeth. This method of age estimation is of particular value as it can be applied to living individuals and dead bodies, where bone level can be measured directly from the skulls of unidentified bodies if imaging technology is not available.

Gustafson's method, which focuses on six regressive changes has been modified and evaluated in several studies of extracted teeth\(^{21}\) and as well as radiographs.\(^{19}\) In the present study, only three regressive changes (attrition, secondary dentine formation and periodontal recession) were selected as the other three remaining changes are not clearly seen on CBCT images. In comparison to study reported by Olze et al.,\(^{13}\) this present study is able to include stage 3 of attrition and stage 3 of secondary dentine which were not found in the study employing the dental panoramic tomographs. To verify the work done by Olze et al.,\(^{13}\) it may be necessary to manipulate the premolar image using the Maximum Intensity Projection (MIP) function in the CBCT machine, so as to obtain direct volume rendering of this tooth, similar to what was offered on the dental panoramic tomographs.\(^{22}\)

As one of the advanced modalities in dental imaging, CBCT is now an important scanning machine for dental diagnosis and prognostic evaluation as the images formed were in 3-dimensional.\(^{19}\) In this present study, it is evident that CBCT images are useful for dental age assessment as bone level measurement was highly correlated with chronological age. This supported the prediction of Maret et al.\(^{19}\) who predicted the usefulness of this machine for age-estimation. Yang et al.\(^{23}\) have even reported volume matching of teeth imaged by CBCT for dental age estimation. Furthermore, unlike in medicine, where the majority of advanced imaging procedures are performed under the supervision of and interpreted by board-certified medical radiologists, most CBCT scans in dentistry are performed in-office by dental practitioners.\(^{24}\)

![Fig. 6. Linear graph of chronological age versus buccal bone level (right).](image-url)
CBCT technology will therefore, most likely, become a distributed diagnostic technology with a high degree of penetrance in clinical dental practice whereby ready availability of the images will be possible for identification and also further beneficial researches.25

5. Conclusion

From the results of this study, it may be concluded that measurement of buccal bone level from CBCT correlated best with chronological age. Therefore, buccal bone level is suitable for forensic age estimation if at least the selection criteria are respected. Moreover, if imaging technology is not available, forensic age estimation can be done by direct measurement of bone level on skulls of unidentified bodies.

6. Limitation

Samples obtained for the older age group were not sufficient compared to the younger age group. Thus, the results may have to be used cautiously as an age indicator in the older age group. Moreover, the quality and geometrical accuracy of CBCT images must be excellent in order for us to accept the CBCT images for any further research.

7. Recommendation

Future research with focus on Gustafson's criteria should be conducted employing Maximum Intensity Projection (MIP) function of the CBCT for more accurate measurement. We will be looking into this possibility in order to validate the work done by Olze et al. (13) to confirm whether “whole tooth” image provides better correlation to Gustafson’s criteria in comparison to sliced images (measuring at a voxel size of only 0.3 mm) in the centre of the tooth.

Conflict of interest

The authors have no relevant conflicts of interest to declare.

Acknowledgements

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Table 5

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Formula</th>
<th>R</th>
<th>R²</th>
<th>Standard error of estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attrition + Secondary dentin formation + Periodontal recession (MRA)</td>
<td>Age = 33.79 × 15.30 + AT + 15.21 × SE + 7.74 × PE</td>
<td>0.48</td>
<td>0.23</td>
<td>12.12</td>
</tr>
<tr>
<td>Attrition (LRA)</td>
<td>Age = 23.95 × AT + 28.64</td>
<td>0.62</td>
<td>0.39</td>
<td>10.92</td>
</tr>
<tr>
<td>Secondary dentin formation (LRA)</td>
<td>Age = 21.29 × SE + 30.06</td>
<td>0.48</td>
<td>0.23</td>
<td>12.19</td>
</tr>
<tr>
<td>Periodontal recession (LRA)</td>
<td>Age = 19.96 × PE + 27.24</td>
<td>0.57</td>
<td>0.32</td>
<td>11.46</td>
</tr>
<tr>
<td>Buccal bone level (LRA)</td>
<td>Age = 7.74 × BL + 10.05</td>
<td>0.82</td>
<td>0.68</td>
<td>7.16</td>
</tr>
</tbody>
</table>

AT stages of attrition, SE stages of secondary dentine formation, PE stages of periodontal recession, BL bone level (mm), R correlation coefficient, R²coefficient of determination.

Multicollinearities were not present as all VIF values fell below the critical value of 4 (Table 6).

Table 6

<table>
<thead>
<tr>
<th>VIF</th>
<th>AT</th>
<th>SE</th>
<th>PE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left side of jaw</td>
<td>1.042</td>
<td>1.023</td>
<td>1.037</td>
</tr>
<tr>
<td>Right side of jaw</td>
<td>1.050</td>
<td>1.011</td>
<td>1.057</td>
</tr>
</tbody>
</table>

AT stages of attrition, SE stages of secondary dentine formation, PE stages of periodontal recession.

