EVALUATION OF ALVEOLAR BONE LOSS MEASUREMENTS IN ADULTS FOR AGE ESTIMATION

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DOI: https://dx.doi.org/10.4314/gdj.v22i1.3

ABSTRACT

BACKGROUND: Identification and age estimation are very important in forensic medicine, anthropological sciences and law. Evaluation of tooth development is one of the most commonly used methods for age estimation. The accuracy of age estimation methods used in the advanced age range gradually decreases. Besides, whatever methods are used, the biggest limitation of age-at-death evaluation is that there is no identification method for the elderly.

PURPOSE: This study aims to investigate the applicability of buccal alveolar bone level in estimating chronological age using Cone Beam Computed Tomography images.

METHODS: In this study, linear measurements of buccal bone loss on coronal section images were acquired using cone beam computed tomography images of mandibular premolar teeth of 200 females and 189 males between 20 and 82 years old, without considering their medical conditions.

RESULTS: A statistically significant relationship was found between age and all mandibular premolar parameters ($p<0.05$). Age estimation was more accurate when all teeth were used. No statistical differences between the left and right teeth ($p=0.172$, $p=0.584$) were found, but gender significantly affected the independent variables, with males showing higher BBL values ($p=0.008$, $p<0.001$, $p=0.006$, $p=0.016$).

CONCLUSION: The results suggest that BBL is correlated with age and can be used for forensic age estimation.

KEYWORDS: Age estimation, Alveolar bone loss, Buccal bone level, Cone-Beam Computed Tomography, Forensic science.

INTRODUCTION

Forensic age estimation is the scientific process of estimating chronological age by evaluating skeletal and dental development [1]. It is used to identify criminals, illegal immigrants, and human remains [2]. Especially in law and archeology, it is extensively used in administrative and medical applications as it is considered a basic parameter that enables the identification of living or deceased individuals [3].

In forensic cases, it is crucial to focus on smaller, easily accessible parts of the body to estimate age while ensuring the methods are both accurate and reliable. Furthermore, forensic sciences must consider the time factor and age estimation should be available quickly, within days or hours, when the investigation needs it [4].

Evaluation of dental and skeletal development are among the most frequently used methods in age estimation; however, skeletal development is affected by numerous variables such as race, congenital syndromes, endocrine system disorders, nutrition disorders, systematic diseases, and environmental and geographical factors [5]. Furthermore, these techniques are based on the evaluation of skeletal development and degeneration and usually produce a more comprehensive and indefinite age range for individuals above 50 years of age. Age estimation methods in which teeth are used, on the other hand, give more accurate results than other methods because the teeth are preserved for a longer time and show less change after the separation of bones and tissues [6].

Cone Beam Computed Tomography (CBCT) examinations provide essential information for the quantitative examination of dental tissues and are widely used. Despite the significant purpose of it being clinical diagnosis and prognostic evaluation, CBCT data can be beneficial in defining new parameters in dental development phases and quantitative description of crown and root sections, moreover presenting new research opportunities that are intended for various aspects of jaws and teeth under favour of large sample opportunities [7]. It is stated that the advantage of CBCT according to the intraoral periapical and panoramic view in dental age estimation originates from the presence of three-dimensional multiplanar navigation that enables the more detailed observation of morphological features [8].

In various studies about age estimation, mandibular premolar teeth are preferred to other teeth because of their more excellent resistance to destruction compared to incisors and their predominantly single-rooted morphology compared to molar teeth [9-10].

In this study, it was aimed to obtain regression models based on linear measurements of buccal bone loss (BBL) in coronal sections using Koh et al's [10] method for CBCT imaging of mandibular premolar teeth. Eventually, it aims to develop a simple, standardized, reliable and reproducible technique to determine whether the obtained models can be used to predict gender and age in forensic odontology in adult Turkish population.

METHODOLOGY

The study retrospectively reviewed CBCT images of patients who underwent diagnostic examinations at the Ankara University Faculty of Dentistry, Department of Oral and Maxillofacial Radiology, between 2012 and 2018.The Ankara University Faculty of Dentistry Clinical Research Ethics Committee approved this study on 30/01/2018 (Approval No: 36290600/09).

Sample Selection

CBCT images of individuals aged 20 and older with mandibular premolar teeth were included. The inclusion criteria were fully erupted mandibular premolar teeth with fully developed roots. Exclusion criteria included underexposed images containing developmental and morphological anomalies, such as caries, erosion, fracture, impaction, restorations, canal fillings, malocclusion, or apical lesions.

Imaging Protocol

CBCT images were obtained using the Planmeca ProMax 3D Max ProFace (Helsinki, Finland) CBCT scanner. The imaging protocol followed field of view (FOV) sizes ranging between 130 x 130 mm and 100 x 59 mm, with exposure settings standardized at 90-96 kVp, 5-11 mA, an average scan time of 12 seconds, and a voxel size of 200 μm. All CBCT images were exported in DICOM format using Planmeca Romexis Viewer Launcher software, version 4.4.0.0, for further analysis.

Measurement of Buccal Alveolar Bone Loss (BBL)

The buccal alveolar bone loss (BBL) measurements were performed using the ruler provided by Planmeca Romexis Viewer software, which allows accurate measurement of linear distances in CBCT images. BBL was defined as the vertical distance between the enamel-cementum junction (ECJ) and the highest point of the alveolar bone on the buccal surface of the tooth [10] (Fig.1). The measurements were taken in millimeters (mm).

Figure 1: Recordings of the measurements

For consistency, all measurements were made on coronal sections of the CBCT images, with the measurements performed in the vertical midline of the buccal surface of the tooth. Each tooth was measured at least three times, and the average of these three measurements was recorded for analysis. If both left and right premolar teeth were available, measurements were taken from both sides.

Instrumentation and Conditions

Images were analyzed on a medical monitor (NEC MD213MG) with high-resolution settings under consistent low-light conditions to minimize visual strain and enhance measurement accuracy. To avoid bias, all measurements were conducted blindly, without knowledge of the patient's age or gender.

Inter-Observer and Intra-Observer Reliability

To ensure the reliability of the measurements, two independent observers conducted them twice at different times. The intraclass correlation coefficient (ICC) was calculated to assess both inter-observer and intra-observer reliability. Inter-observer and intra-observer reliability was over 90% ($p > 0.05$), indicating that the measurements were highly reproducible.

Statistical Analysis

All statistical analyses were performed using SPSS 20 (IBM et al., USA). Descriptive statistics were performed. Quantitative variables were summarized as means and standard deviations. The influence of gender on independent variables was tested using an independent two-sample t-test. Similarly, a two-sample t-test was used to determine whether the value obtained from left premolars was comparable to that obtained from right premolars. Pearson's correlation coefficient was used to assess the correlation between age and BBL, and multiple regression analysis (MRA) was conducted with biological age as the dependent variable and BBL and gender as independent variables. Intraclass correlation coefficient (ICC) was calculated to test the intra-observer and inter-observer. A p-value < 0.05 was considered statistically significant.

RESULTS

This retrospective study is based on 389 CBCT scans. Patients were selected among from who applied to Ankara University Faculty of Dentistry, Department of Oral, Dental and Maxillofacial Radiology and those CBCT examinations were taken only for routine diagnosis. The individuals were between 20 and 82 years old, of which 200 were female and 189 were male and divided into five age groups. The age distribution of the first four groups continued ten years apart, while our last group consisted of individuals aged 60 and over. Statistical distribution of gender and age groups are shown in Table 1.

Table 1. Statistical distribution of age and gender groups.

	Gender					
	Females		Males		Total	
Age Range	Number	Percentage	Number	Percentage	Number	Percentage
20-29	40	20.0%	40	21.2%	80	20.6%
30-39	40	20.0%	40	21.2%	80	20.6%
40-49	40	20.0%	40	21.2%	80	20.6%
50-59	40	20.0%	38	20.1%	78	20.1%
60 & above	40	20.0%	31	16.4%	71	18.3%
Total	200	100.0%	189	100.0%	389	100.0%

In this study we assessed 355 left mandibular second premolars (# 35), 379 left mandibular first premolars (#34), 381 right mandibular first premolars (#44) and 359 right mandibular second premolars (#45). Table 2 shows the distribution of teeth according to gender.

Table 2. Gender distribution of the evaluated teeth.

Tooth	35(n)	34(n)	44(n)	45(n)
Females	179	193	199	183
Males	196	186	182	176
Total	359	381	379	355

Intra-observer and inter-observer reliability between two observers was assessed by ICC. The inter-observer reliability of BBL measurements was found to be over 90% ($p>0.05$), and the intra-observer reliability was found to be 99.5% ($p>0.05$), indicating that the measurements were statistically reproducible.

To investigate whether there is an impact of gender on independent variables, a two-sample t-test was used, and p-value was set <0.05. The p-value was significant for all our measurements, and it was concluded that gender had a statistically significant effect on our findings. This allows gender to be used as an independent variable in obtaining regression models for age estimation. According to our data, the average BBL values that belong to each mandibular premolar tooth were higher in males (Table 3).

Table 3. Independent two-sample t-test results that show whether gender has an impact on independent variables.

Tooth	Gender	BBL	p
35	F	2.38±1.40	0.008
	M	2.81±1.61	
34	F	2.52±1.34	<0.001
	M	3.09±1.63	
44	F	2.63±1.56	0.006
	M	3.08±1.59	
45	F	2.36±1.53	0.016
	M	2.73±1.42	

F: Female, M: Male, BBL: Buccal bone loss, p: significance value.

An independent two-sample t-test was used to test whether there is a statistical difference between BBL linear measurements among the symmetrical ones from the left and right teeth. Our results concluded that there is no statistical difference between left and right teeth for all values ($p>0.05$). This situation ensures that average values of left and right dental measurements can be used as independent variables while obtaining regression models that will be created for age estimation. Average and standard errors and p-values of measurements are shown in Table 4.

Tooth	Average	n	SD	p value
35	2.493313	330	1.483686	0.172
45	2.418936	330	1.411840	
34	2.768113	371	1.498375	0.584
44	2.795472	371	1.552505	

p: significance value, n: number, SD: Standard deviation

According to our findings, correlated and close values were obtained between age and the teeth (#34, #35, #44, #45). The highest correlation was obtained using the values' average (R2 = 0.717). All our findings were found to be correlated with age ($p<0.05$). R^2 describes the power to represent data in regression analysis; the higher the R2 obtained in the regression analysis, the stronger the equation. The standard deviation of estimation and R from the model summary and the regression models that were obtained in the ANOVA table and R2 and p-values regarding these models were shown in the table 5. When the gender was coded, it was taken as (1 = male, 2 = female).

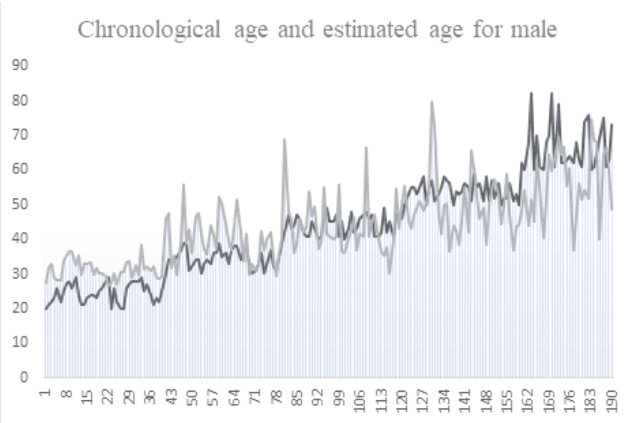
Table 5. Multiple regression models that belong to each one of dental group.

Tooth	Multiple Regression Model	R	R^2	SD	p
35	Age=24.810+2.986(gender)+6.232(BBL)	0.656	0.430	10.826	<0.001
34	Age=23.839+4.361(gender)+6.299(BBL)	0.637	0.405	11.383	<0.001
44	Age=24.863+4.690(gender)+5.767(BBL)	0.623	0.389	11.470	<0.001
45	Age=24.352+3.494(gender)+6.521(BBL)	0.672	0.452	10.652	<0.001
Avg	Age=21.105+4.578(gender)+7.470(BBL)	0.716	0.513	10.450	<0.001

BBL: Buccal bone loss, p: significance value, n: number, SD: Standard deviation, R: Correlation Coefficient, R2: Coefficient of determination, Avg: Average.

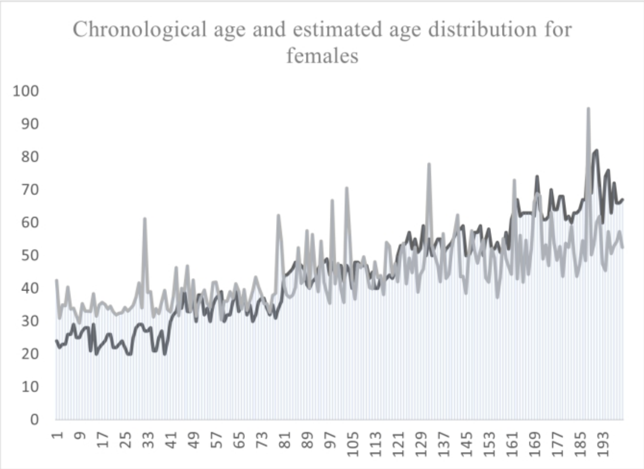
The results of our study indicate that the difference between estimated age and chronological age gradually increases with advancing age as shown in graphs 1 and 2. The trend was observed across both genders, with the closest estimates occurring in the 30s and 40s, while discrepancies became more pronounced after the 50s.

Graphic 1. Distribution of the difference between chronological age and estimated age for male by years.



Black line: Chronological age; Gray line: Estimated age

Graphic 2. Distribution of the difference between chronological age and estimated age for females by years.



Black line: Chronological age; Gray line: Estimated age

DISCUSSION

The age intended to be estimated for both living and deceased is the physiological age, which can be quite different from the chronological age, and the inconsistency between physiological age and chronological age increases as the aging. Therefore, the accuracy rate of the methods used in advancing the age range gradually decreases [2]. Besides, whatever methods are used, the most significant limitation of age-at-death evaluation is that there is no identification method for the elderly, and accurately determining the age-at-death after 65 is difficult [4].

In this study, we aimed to determine whether there is a relationship between age and BBL by providing a large sample and a balanced age distribution. The sample size was large, but due to the specific demographics of the study participants, the results may not fully represent the Turkish population.

In a previous study [15]] based on the relationship between changes in teeth and aging, it has been reported that metal restorative materials used in treating molars prone to decay are unsuitable because they may interfere with measurements. It is also stated that incisors are not considered suitable for measurements because they are often missing due to periodontal destruction, often lose their crowns due to exposure to high temperatures or external factors, or cannot preserve their original structure. Although they usually have long roots for examination, canine teeth are also not considered suitable for age estimation due to the degree of occlusal wear that varies greatly among individuals due to their contact with other teeth during lateral movements. Generally, teeth, with a basic structure and single root are preferred. Our study used mandibular premolar teeth because they have primary and single-root structures and are the least missing teeth [9,10,15].

The buccal bone level is a parameter that can be measured even in fragmented body remains; it was expressed that it presents an important feature for age estimation [10,16]. It was thought that the measurements of alveolar resorption should be performed from the labial surface because the effects of infection, inflammation, and pathological destruction processes are less responsible in these regions [17].

The literature contains conflicting results in studies investigating the relationship between age and alveolar bone loss (ABL) in adults [16,18,19]. A plausible explanation could be differences in methodology between studies.

Streckfus et al. [18] reported that ABL is seen at a significant level in normal lifespan, regardless of gender. They stated that the amount of bone loss was found to be 0.38 mm every ten years and 1.9 mm in total on average between the ages of 20 and 70 in healthy individuals who have decent mouth hygiene. Similarly, Ruquet et al. [16] and Daluz et al. [19] reported that there was no statistical difference between ABL and gender.

Vom Steeg and Klein [20] reported that men are generally more susceptible to infections caused by various pathogens than women. Nazish Alam et al. [21] reported that these gender differences may be related to poorer oral hygiene, less positive attitudes toward oral health, and dentist visit behavior in men, rather than genetic factors.

This study demonstrated a significant correlation between age and BBL in both males and females. Gender differences were evident, with males showing higher BBL values, which aligns with other research suggesting males are more susceptible to periodontal diseases. In addition, the negative effects of poor oral hygiene on alveolar bone loss have been reported [22]. This will affect age estimation and will be a limitation, as individuals with poor oral hygiene may experience greater bone loss independent of age. Our study demonstrated a significant correlation between age and BBL in males and females. Gender differences were evident, with males showing higher BBL values (#45; $p = 0.016$, #44; $p = 0.006$, #34; $p < 0.001$ and #35; $p = 0.008$) (Table 3). This aligns with other research suggesting males are more susceptible to periodontal diseases, and gender-specific models were obtained using the regression models used in our study. In addition, the adverse effects of poor oral hygiene on alveolar bone loss have been reported [22]. This will affect age estimation and be a limitation, as individuals with poor oral hygiene may experience more significant bone loss independent of age.

In the studies carried out by using different methods in the literature, it was reported that there is no statistical difference between the results of right and left teeth in the jaws [11-14]. Likewise, a statistically significant difference was not found based on the independent two-sample t-test for all our values of BBL measurements between the symmetrical left and right teeth in our study ($p > 0.05$) (Table 4). Thus, it allowed us to use the average values of the measurements of the left and right teeth as independent variables when obtaining the regression models for age estimation, even if there is a single premolar in the lower jaw. It has been concluded that the explanatory power of the regression formula has the highest explanatory power, in which the mean of all independent values is used.

Many studies have shown a significant correlation between age and ABL in adults [10,16,18,19]. Our results align with similar studies investigating the relationship between aging and ABL. In a previous study investigating the relationship between ABL and aging by Streckfus et al. [18], mesial and distal sections of the left and right mandibular and maxillary posterior teeth measurements were carried out on intraoral bitewing radiographic combined with clinical examination in 229 adults. Streckfus et al. reported that the R2 value for mandibular ABL was between 0.38 and 0.40. Their results close to our findings.

Ruquet et al. [16] used computed tomography (CT) images of 397 adult individuals, excluding individuals with periodontal disease. This study calculated the amount of ABL on the mesial and distal surfaces of six teeth (16, 21, 24, 36, 41, and 44) called Ramfjord's [22] teeth. In Ruquet's study [16] the R value was 0.69 and the R2 value was 0.48, which was close to our findings. Furthermore, according to the results of this research, it was emphasized that their method was more effective between the ages of 25-55 and our results were found to be coherent with their study.
In Koh et al.'s [10] study which used a similar methodology, CBCT imaging of 284 cases was used. The R2 value for the BBL on the right side of the mandible was found to be 0.68, and the R2 value on the left side was 0.72, which is higher than our findings. In this study, it was stated that the buccal bone level is highly correlated with chronological age. Therefore, it can be safely concluded that it is the most appropriate age-related characteristic for forensic age estimation.
In a study by Daluz et al. [19] in which Ruquet's ABL method was re-evaluated using three-dimensional imaging (CT and CBCT), it was reported that the ABL index was significantly associated with age. The Pearson correlation coefficient (R) was found to be 0.78 ($p < 0.001$) between age and ABL with all teeth and 0.75 ($p < 0.001$) between age and ABL of Ramfjord's teeth, which is consistent with our study. These results show that, although different analysis methods were used and the studies were based on the analysis of different regions within the jaw, ABL is associated with aging and is an important parameter that can be used in age estimation.
In a study by Daluz et al. [19] in which Ruquet's ABL method was re-evaluated using three-dimensional imaging (CT and CBCT), it was reported that the ABL index was significantly associated with age. The Pearson correlation coefficient (R) was found to be 0.78 ($p < 0.001$) between age and ABL with all teeth, and 0.75 ($p < 0.001$) between age and ABL of Ramfjord's teeth, which is consistent with our study. These results show that, although different analysis methods were used and the studies were based on the analysis of different regions within the jaw, ABL is associated with aging and is an important parameter that can be used in age estimation.
In our study, a significant correlation was found between our findings for each mandibular premolar tooth that we examined on CBCT images and age in the statistical aspect. Since the formulas obtained are gender-specific, we think we can contribute to narrowing the estimation circle even in cases where only mandibular teeth are obtained in the forensic context. However, it should be noted that the quality of CBCT images limits the applicability of the presented method. Nevertheless, the presented age estimation method is precious where imaging technology is not available because bone level can be measured directly from the skulls of unidentified corpses, as well as in living individuals. Our method matches the reality of the forensic field, which prefers simple, fast, inexpensive, equipment-free, and easy-to-use methods.
It has been reported that for the acceptability of the accuracy of methods studied in different population groups for adult dental age estimation by forensic scientists, ideally, the standard deviation (SD) should not exceed the threshold of ± 10 years [23–25]. It was observed that our results were close to the limits. The standard deviation of our age estimation for both genders was found to be at an acceptable level by forensic sciences. As seen in graphics 1 and 2, according to the results of our study, the difference between estimated age and chronological age gradually increases with advancing age. It seems that the closest age estimates are obtained in the 30s and 40s, and after the 50s, the difference is becomes even more comprehensive. Our results appear to be consistent with the authors[2,4].

CONCLUSION

This study demonstrates that BBL, measured from CBCT images of mandibular premolars, is a reliable marker for chronological age estimation in forensic applications. The regression models developed, particularly those based on average BBL values, demonstrate predictive solid accuracy, with gender significantly affecting the results. No statistical differences between the left and right mandibular premolars were observed, enabling using either side for age estimation. However, the method is limited by the quality of CBCT images and variations in oral hygiene, which may influence bone loss independently of age. Despite these limitations, the BBL-based approach offers a practical, non-invasive method for age estimation, especially in cases with limited dental remains. Future advancements in CBCT technology and further research exploring additional teeth and alternative imaging techniques could refine and enhance the accuracy of this method in forensic science.

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