Alveolar bone height and thickness assessed by CBCT

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Objectives: To seek information regarding the relationship between the quantity of alveolar bone and the angle and sagittal position of the incisors. This was to be further determined in relation to the basal bones and facial pattern with the aim of establishing a predictive model based on the study of a lateral cephalogram.

Methods: The distance from the cemento-enamel junction to the labial alveolar crest and the bone thickness half-way along the root of the most prominent upper and lower incisor were measured in a sample of 100 cone beam computed tomography (CBCT) scans of patients aged between 15 and 34 years. Lateral cephalograms of the patients were extracted from the scans and used to measure the buccolingual angle and antero-posterior position of the incisors in addition to the facial pattern of each patient.

Results: A correlation was found between bone thickness around the upper incisor and the variables of the incisal angle and its sagittal position. The inclination of the lower incisor (IMPA) was related to cortical bone thickness. The cemento-enamel junction to alveolar crest measurement (bone height) was related to the antero-posterior position of the lower incisor in men. The facial pattern was unrelated to any of the variables.

Conclusions: The angle and sagittal position of the upper and lower incisors were associated with alveolar bone thickness in men. Only the antero-posterior position of the lower incisor was related to its alveolar bone height. In women, only the angle of the lower incisor was associated with bone thickness.

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Introduction

In order to determine a correct orthodontic diagnosis and definitive treatment objectives, it is important to ascertain the spatial position of the incisors relative to their basal bone. An excessive labio-lingual angle or unfavourable sagittal position of the incisors can lead to gingival recession,1 dehiscence and/or fenestration on the labial aspect of the alveolar bone surrounding these teeth.2-4

Lateral cranial radiography is a useful tool for measuring and interpreting incisal parameters.5-8 Nevertheless, detecting the amount of bone or the presence of a fenestration from a lateral cephalogram can be difficult and the results may be inexact because of overlapping structures. Using cone beam computed tomography (CBCT) to measure the height and thickness of alveolar bone9-12 provides more accurate information.10 Unfortunately, the process delivers a higher radiation dose, and so it cannot be employed indiscriminately and without justification.13

Although the relationship between the position of the incisors within their basal bone and the quantity of alveolar bone has been widely studied, controversies persist.1-4,14-18 For example, several reports have found a relationship between the appearance of gingival recession and the position of the lower incisors,1 while others have disputed this relationship.14,15,19

In addition, research has sought a relationship...
between the height and thickness of the alveolar bone and skeletal class, facial pattern,\textsuperscript{19,20-23} age\textsuperscript{19,24} and smoking.\textsuperscript{11,24}

Because of the lack of consistency in the measurement of relationships between the buccolingual angle, the sagittal position of the incisors and other variables, it has proved unreliable to estimate the quantity of cortical bone through cephalometric studies.

The objectives of the present study were to ascertain whether the facial pattern and the angle and position of the incisors with respect to their basal bones are related to the height and thickness of the alveolar bone, in order to determine if bone quantity can be predicted through the examination of corresponding parameters on a lateral cephalogram.

Material and methods

The research was approved by the Human Research Ethics Committee of the University of Valencia (registration number H1426674729663). All of the patients provided their informed consent.

A sample of 100 CBCT scans was obtained from the University of Valencia database. Each scan had been taken independently of this research for diagnosis and treatment planning purposes. All scans used in this study, which followed the current European Radiation Protection Guidelines,\textsuperscript{25} were taken using a Planmeca ProMax\textsuperscript{®} 3D machine (Planmeca, Helsinki, Finland) at 90 kV, with a voxel size of 0.4 mm, a field of view of 18 $\times$ 20 cm and a scan time of 18 seconds. The selected patients were aged from 15 to 34 years and the following exclusion criteria were applied: patients were omitted from the study if there were signs of periodontal disease, if they were smokers or if they had missing teeth in the anterior sextants.

The facial alveolar bone height and thickness measurements were obtained from the CBCT scans using Invivo Dental 5 software (Anatomage, CA, USA).

The most labial upper and lower incisors were selected from the axial view. The images were oriented along the long axis of the incisors in the coronal and sagittal planes and a sagittal cross section was produced (Figure 1). The following variables were subsequently measured (Figures 2 and 3):

- **BHUI** (Bone Height Upper Incisor) and **BHLI** (Bone Height Lower Incisor): The length in millimetres from the cemento-enamel junction (CEJ) to the most incisal point of the alveolar bone in contact with the root surface of the upper and lower incisors respectively.
- **BTUI** (Bone Thickness Upper Incisor) and **BTLI** (Bone Thickness Lower Incisor): The alveolar bone thickness

\textbf{Figure 1.} Orientation of the CBCT image along the long axis of the selected incisor. A sagittal section of the tooth was obtained.
of the upper and lower incisors, respectively. This was the distance in millimetres from the incisor root surface to the most external point of the labial cortical bone. This measurement was determined from a line perpendicular to the axis of the tooth, halfway between the CEJ and the tooth apex. For parameter measurement, two horizontal parallel lines were drawn, one at the level of the CEJ, the other at the tooth apex. The distance between the lines was halved and a third horizontal line was constructed at that level. Thickness measurements were made on the constructed line.

Using the Invivo Dental 5 software, lateral cephalograms were generated from the CBCT scans. The angle and sagittal position of the upper and lower incisors and the FMA were measured on the radiographs using the Dolphin Imaging program (Dolphin Imaging and Management Solutions, CA, USA). These variables were measured according to the following (Figure 3):

PPUI and IMPA (Upper Incisor – Palatal Plane Angle and Lower Incisor – Mandibular Plane Angle): The buccolingual angle of the incisors. The variables measured the angles between the palatal plane and the axis of the upper incisor and between the mandibular plane and the axis of the lower incisor.7,8

A-UAXIS and B-LAXIS: The sagittal position of the incisors. The distance in millimetres between point A and the axis of the upper incisor on a line perpendicular to this axis and between point B and the lower incisor axis.

FMA: The angle formed by the Frankfort and mandibular planes.7

The examiner was calibrated by a ‘gold standard’ instructor who had considerable experience in obtaining measurements from CBCT scans. The calibration was performed on 20 patients and resulted in an intra-class correlation coefficient of over 0.85. After all the measurements had been performed, intra-examiner reproducibility was tested, resulting in an ICC of over 0.80.

Univariate descriptive statistics were calculated for the quantitative variables, including means at 95% confidence intervals. The Kolmogorov-Smirnov’s test was applied to check for normal data distribution. The Student’s t-test was used to check for differences between the means. The linear correlations between the quantitative variables were measured by Pearson’s correlation test. A multivariate linear regression analysis was conducted using a stepwise method to determine significant variables included in the model. The significance level was set at $p = 0.05$.

The size of the sample ($N = 98$) was based on a two-tailed test with a 95% ($\alpha = 5\%$) confidence level, for statistical power 80% ($\beta = 20\%$), to achieve a minimum difference of 2º with a variance of 25.
Results
The sample consisted of 100 CBCT scans of 36 men and 64 women with an average age of 23.6 years (SD ± 7.3). The descriptive data by gender for the variables studied are provided in Table I. Significant differences were found in BHUI, which was greater in men than in women.

Pearson’s correlation coefficient showed significant upper incisor correlations between BTUI and BHUI and A-UAXIS and between PPUI and BTUI and A-UAXIS (Tables II and III). The highest correlation for the lower incisors was a negative relationship between IMPA and BTLI (Pearson = -0.230) (Tables II and III).

Table IV shows the linear regression models, which used bone height and thickness in men and women as the dependent variables. The only female predictor of bone thickness around the lower incisors (BTLI) was IMPA. PPUI and the A-UAXIS were both predictive variables for BTUI in the male upper incisors and for B-LAXIS and IMPA in the lower incisors.

The only predictive variable for bone height was the B-LAXIS of the lower arch in men. The independent analysis found no predictive variable for BHUI in either gender.

FMA showed no significant association with the dependent variables studied.

### Table I. Distribution of cephalometric measurements (mean and 95% CI).

|          | Women N = 64 Mean (CI 95%) | Men N = 36 Mean (CI 95%) | N = 100 Mean (CI 95%) | Student’s t Test |
|----------|-----------------------------|---------------------------|-----------------------|------------------|
| Age (years) | 23.56 (20.94–26.19) | 23.65 (21.81–25.43) | 23.6 (22.1–25.1) | 0.175          |
| BHUI (mm)  | 1.55 (1.36–1.74) | 2.51 (1.60–3.43) | 1.90 (1.55–2.25) | 0.000*          |
| BTUI (mm)  | 2.93 (2.42–3.44) | 0.83 (0.65–1.02) | 0.86 (0.77–0.95) | 0.084          |
| PPUI (°)   | 0.43 (0.29–0.57) | 0.63 (0.38–0.89) | 0.51 (0.38–0.63) | 0.239          |
| A-UAXIS (mm) | 4.62 (4.23–5.01) | 4.97 (4.46–5.48) | 4.74 (4.44–5.05) | 0.879          |
| B-LAXIS (mm) | 3.05 (2.80–3.29) | 0.92 (2.65–3.19) | 3.01 (2.82–3.18) | 0.019          |
| IMPA (°)   | 92.7 (90.5–94.8) | 90.9 (88.4–93.4) | 92.1 (90.4–93.6) | 0.515          |
| FMA (°)    | 23.7 (22.3–25.0) | 23.3 (21.3–25.3) | 23.5 (22.4–24.6) | 0.744          |

* p < 0.05

### Table II. Pearson’s correlation for upper incisor.

|          | BTUI | A-UAXIS | PPUI | FMA | Age |
|----------|------|---------|------|-----|-----|
| BHUI     | -0.257*** | -0.007 | -0.026 | 0.036 | 0.072 |
| BTUI     | 0.281*** | 0.261** | 0.261** | 0.150 | 0.114 |
| A-UAXIS  | 0.533*** | 0.042 | 0.042 | 0.077 |
| PPUI     | 0.158 | -0.143 | -0.143 | 0.050 |

* p < 0.05, ** p < 0.01
Discussion

The present study was conducted to determine whether the angle and position of the incisors and the height and thickness of the alveolar bone are related. The results have shown that this information may be obtained through a lateral cephalogram assessment, thereby avoiding the need to resort to measurement of CBCT scans.

CBCT is a diagnostic tool that has shown its validity for measuring alveolar bone and identifying the presence of bone dehiscences and fenestrations. According to Sun et al., although deviations of 0.4 and 0.6 mm were found when locating the CEJ and bone margin respectively, CBCT is a highly sensitive and specific method.

However, it presents disadvantages, such as greater costs for the patient and orthodontist and a higher radiation dose, so justifiable reasons are needed for its use.

The height and thickness of the facial alveolar bone surrounding the upper and lower incisors are indicators of periodontal health and of the prognosis for these teeth. Many factors may be involved in the quantity of cortical bone and ageing is related to a loss of periodontal support. Persson et al. studied the horizontal and vertical quantity of alveolar bone in individuals aged between 15 and 94 years and found that both height and thickness remained stable between 15 and 34 years of age. Based on this, the sample used in the present study comprised scans of 15- to 34-year-old patients in order to remove the ageing factor.

The present study investigated the relationship between the quantity of cortical bone relative to the position of the incisors. The methods used to measure alveolar bone thickness and height from the CBCT scans were based on the methodology of previously published papers. Nahás-Scocate et al. investigated the relationship between the angle of the upper incisor (using the angle between the upper incisor axis and the palatal plane) and the quantity of labial cortical bone. It was concluded that bone thickness at the apical level increased in line with an increase in that angle. The present study also found a statistically significant relationship between these two variables, as indicated by the A-UAXIS/palatal plane correlation.
The relationship between the position of the lower incisor and the thickness of the alveolar bone was studied by Yu et al. and Yamada et al. Both reported similar results, showing the existence of a relationship between the angle of the lower incisor and the thickness of the cortical bone. This agrees with the findings of the present study, in which the IMPA and labial bone thickness exhibited a strong correlation.

Despite numerous papers analysing the relationship between the buccolingual angle of the incisors and the quantity of bone surrounding these teeth, a review of the literature found none that reported the relationship between the cortical bone and the sagittal position of the incisors. Consequently, the variables of antero-posterior position of the incisors (A-UAXIS and B-LAXIS) were included in the design of the present study. The measurements undertaken to establish the position of each of the incisors with respect to its basal bone were decided ad hoc. Those described in the literature measured their position in relation to the base of the cranium or to the opposite jaw, which can give a false impression of the exact position of the tooth. The present study also used the axis of the tooth as a reference line, instead of the incisal edge as described by many, in order to avoid distortions due to irregularities affecting the anatomical crown.

No mention of investigating the relationship between alveolar bone height and incisor position was found in the literature. These measurements also were included in the present study but, owing to the absence of previous studies, no comparison with the present findings was possible.

In the present study, associations between vertical pattern and bone morphology were made. FMA was used for assessing the vertical pattern as it has been proved to be a highly sensitive indicator. Gracco et al. conducted a study to ascertain whether there was a relationship between facial patterns and the thickness and height of cortical bone. This study classified the facial pattern through measurement of FMA and found an association between facial pattern and labial alveolar bone thickness at the upper central incisors, observing that the cortical bone was thicker in brachyfacial compared with dolicho facial patterns. However, Evangelista et al. found no differences between different facial patterns and the presence of bone dehiscences and fenestrations. The present study found no relationship between the facial pattern measured by the FMA and any of the bone morphology variables investigated.

One of the objectives of the present study was to establish a predictive model for the assessment of alveolar bone height and thickness based on a cephalometric study. To this end, linear regression was used to analyse the results. In females, the lower incisor angle served as a predictive variable for bone thickness around that tooth. In males, the angle and sagittal position of the upper and lower incisors served as predictive variables for bone thickness. The only variable that showed predictive behaviour related to BHLI was B-LAXIS. The facial pattern did not serve as a predictive variable for either the height or the thickness of the alveolar bone in either gender.

It has been considered that age and gender influence the height and thickness of the bone, which is why the particular age range was chosen. For the same reason, the linear regression analysed men and women separately.

Tobacco consumption has been shown to be directly related to bone loss. To control this variable, smokers were excluded from the present study.

The skeletal classification is an additional variable that has been related to the quantity of cortical bone. Yagci et al. found significant differences in the presence of fenestrations, but not dehiscences, between skeletal Classes I, II and III. In a similar study, Evangelista et al. encountered more bone defects in skeletal Class I patients than in Class II patients. The studies by Yagci et al. and Evangelista et al. followed Handelman in defining bone dehiscences as vertical bone defects measuring over 2 mm.

The limitations of the present study include the failure to take skeletal class into account. However, this factor was included indirectly, as it can be related to the antero-posterior compensated position of the incisors, which were identified through measuring the variables of incisor angle and sagittal position. Additional longitudinal studies could be used to measure changes in bone height and thickness during orthodontic treatments.

Conclusions

According to the results of the present study, it may be concluded that in males, the angle and sagittal position of the upper and lower incisors show an association with alveolar bone thickness. Only the antero-posterior position of the lower incisor is associated with bone height. In females, the angle of the lower incisor is associated with bone thickness.
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